Physical Preparation for Fencing:

Tailoring Exercise Prescription and Training Load to the Physiological and Biomechanical Demands of Competition

Anthony N. Turner

Doctor of Philosophy

Middlesex University

School of Science and Technology

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Abstract

Sport science based research regarding fencing competition demands and athlete physical characteristics (PC) is sparse; as a consequence, training programme design cannot be optimised. The aim of this PhD thesis therefore, is to describe the PC that best relate to (1) lunge velocity (LV), (2) change of direction speed (CODS) and (3) repetitive lunging ability (RLA). It also sought to analyse (4) the physiological intensity and associated fatigue of competition and (5) the efficacy of the subsequently delivered periodised training programme. Fencers from the Great Britain Fencing squad were investigated. Results revealed that LV and CODS were best predicted by the standing broad jump (SBJ) (r = 0.51 and -0.65 respectively). Through linear regression analysis, CODS and SBJ provided a two-predictor model accounting for 61% of the common variance associated with RLA. Competition intensity and fatigue was measured across two competitions, including subsequent recovery days, where countermovement jump (CMJ) scores and saliva samples (measuring testosterone, cortisol, alpha-amylase and salivary IgA) were taken. On the day of competition, all fencers had their heart rate (HR) recorded and had blood lactate (BL) and rating of perceived exertion (RPE) measured after each bout. Average (± SD) scores for RPE, BL and HR (average, max and percentage of time ≥ 80% HRmax) were highest in the knockout bouts compared to the pools (8.5 ± 1.3 *vs.* 5.7 ± 1.3, 3.6 ± 1.0 *vs.* 3.1 ± 1.4 mmol/L, 171 ± 5 *vs.* 168 ± 8 bpm, 195 ± 7 *vs.* 192 ± 7 bpm, 74 *vs.* 68% respectively), but only significantly ($p < 0.05$) so in RPE. CMJ scores measuring jump height, peak power (PP) and peak rate of force development, increased throughout the competition and dropped thereafter. For jump height and PP, the post-knockout score was significantly higher than pre-competition scores, and all scores taken at competition were significantly higher than post-

competition scores. No significant differences were noted across time-points for any of the measured salivary analytes. Finally, the efficacy of the training programme, designed following the findings of the preceding studies, was analysed. RPE, HR and BL scores from competition bouts were compared to that recorded in training sessions aimed at developing the fencer's sport-specific fitness. Alongside this, CMJ height, reactive strength index and questionnaires regarding "readiness to train" were completed daily and compared to the prescribed training load (TL) as calculated using session RPE. Only "off-feet" non-sport specific conditioning drills were found to provide an appropriate stimulus (with respect to HR, RPE and BL) for competition based fitness. Using multilevel modelling, no relationships between TL, jump scores and questionnaires were noted.

Acknowledgements

I have enjoyed the challenge of this thesis and very proud to have completed. I have learnt a tremendous amount along the way and excited to apply it within my teaching, practice and future research. Of course, I could not have completed it without the help of so many people.

My initial thanks go to my supervisory team, Professor Nic James, Dr. Lygeri Dimitriou and Professor Liam Kilduff. Your advice and support throughout has been invaluable. You have guided my studies and steered my learning. I would also like to thank my Head of Department, Dr. Rhonda Cohen. Your encouragement and our informal chats helped keep me focused. Also, thank you to my colleagues at the London Sport Institute. Always dependable and ready to provide advice and feedback on the numerous problems I faced along the way; they kept the goal in sight.

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Finally, thanks go to my family, my mum, dad, brother and his fiancée, and my wife and two children. In completing this, they gave me a sense of pride far beyond academic achievement. Equally, their help and encouragement stretched far beyond the obvious demands of undertaking a PhD. There were so many achievements that had to first take place before this thesis was even possible, and they were behind every one. Of course, I must give special thanks to my wife Carli, she lived every moment of this with me… we did it!

Collaborations in Producing this Thesis

The completion of this thesis was based on collaborations between Middlesex University, Swansea University and British Fencing. I have worked for British Fencing since 2009, initially this was with what was then called the "National Academy" but now referred to as the "Talent pathway". In 2012 I was appointed head of Physical Preparation for the senior squads and given the keen interest I had developed in the sport, decided to undertake my PhD in this area. The performance director Alex Newton and the fencing athletes of British Fencing were very supportive of me doing this. For example, in study three, during two competitions, athletes had to return to the "sport science station" after every bout and with a very dry mouth, provide me with a saliva sample; they also had to jump and give blood. This was incredible collaboration, including from the fencing coaches who were not only permissive of this, but also helped round up the athletes for testing; I hope the data I uncovered will go some way to returning the favour. I would also like to thank the S&C coaches who helped me collect this data, namely Geoff Marshall, James Phillips, Conor Buttigieg and Angelo Noto. Also my supervisor Lygeri Dimitriou, who along with Dr Frank Hills, helped me analyse this data back at the university labs. The S&C coaches also helped collect the training load data that was analyzed for volume load prescription as described in study four.

As well as the support of British Fencing and my colleagues at the university, I also asked Professor Liam Kilduff of Swansea University to supervise my studies. Professor Kilduff is a renowned expert in the field of sports physiology and his guidance was invaluable. I hope to continue working with Professor Kilduff and learning from him for many more years.

Publications and Presentations from this Thesis

Turner, A., Miller, S., Stewart, P., Cree, J., Ingram, I., Dimitriou, L., Moody, J., Kilduff, L. (2013). Strength and Conditioning for Fencing. *Strength and Conditioning Journal , 35* (1), 1-9.

Turner, A., James, N., Dimitriou, L, Greenhalgh, A., Moody, J., Fulcher, D., Mias, E., Kilduff, L. (2014). Determinants of Olympic Fencing Performance and Implications for Strength and Conditioning Training. *Journal of strength and conditioning research , 28* (10), 3001-2011.

On 29th January 2015, the chair of the Journal of Strength and Conditioning Research Manuscript Clarification sub-committee informed me that a rebutal to my review article had been submitted. My paper was challenged (mainly) on the grounds of providing insignificant merit to the training of aerobic capacity. This rebuttal and my response are included in the appendicies (Appendix C) and were published on-line in April 2015.

At the request of British Fencing, no primary research would be submitted for publication until post Rio Olympics, 2016. However, in-house presentations of experimental study one were permitted and thus conference presentations were as follows:

Turner, A. (2013). Identifying and developing the key physical attributes of elite fencers. *British Fencing Club and Coach Conference*, 6 October, Sandown Park, Surrey, UK

Turner, A. (2014). Physical Characteristics Underpinning Fencing Performance. *Middlesex University Summer Conference*, 18 June 2014, London, UK

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List of Abbreviations

1RM	One repetition maximum
AE	Athlete exposures
ANOVA	Analysis of variance
ANS	Autonomic nervous system
APHV	Approximated peak height velocity
AT	Anaerobic threshold
AU	Arbitrary units
BL	Blood lactate
BRUMS	Brunel Mood Scale
C	Cortisol
CG	Centre of gravity
$\dot{V}\,CO_2$	Rate of elimination of carbon dioxide
CODS	Change of direction speed
COVL	Concrete with an overlaid vinyl layer
CV	Coeffiecient of varaition
DALDA	Daily Analysis of Life Demands for Athletes
EMG	Electromyography
ES	Effect size
GAS	General adaptation syndrome
HIIT	High intensity interval training
HPA	Hypothalamic–pituitary–adrenal
HR	Heart rate

HRR	Heart rate recovery
HRV	Heart rate variability
ICC	Intraclass correlation coefficient
IgA	Immunoglobulin A
LV	Lunge velocity
MMA	Mixed martial arts
NE	Norepinephrine
$\dot{V}\,O_2$	Oxygen consumption
$\dot{V}\,O_2max$	Maximum oxygen uptake
OBLA	Onset of blood lactate accumulation
OT	Overtraining
PC	Physical characteristics
PLF	Peak landing forces
POMS	Profile of Mood States
POMS-A	POMS-Adolescents
POPF	Push-off peak force
PP	Peak power
PPu	Plyometric push-up
PRFD	Peak rate of force development
RESTQ-Sport	The Recovery–Stress Questionnaire for Athletes
RFD	Rate of force development
RLA	Repetitive lunging ability
RSI	Reactive strength index
S&C	Strength and conditioning
sAA	Salivary α-amylase

SBJ	Standing broad jump
SLCMJ	Single leg-countermovement jump
SPDBk	Speed back
SPDFwd	Speed forward
SQF	Short questionnaire of fatigue
sRPE	Session ratings of perceived exertion
SSC	Stretch-shortening cycle
T	Tesestosterone
TL	Training load
TLI	Time-loss injuries
TM	Training monotony
TMA	Time-motion analysis
TPF	Time to peak force
TQR	Total Quality of Recovery questionaire
TRIMP	Training impulse
TS	Training strain
URTI	Upper respiratory tract infections
VGRF	Vertical ground reaction force
W : R	Work : rest ratio
WCP	World class performance
WSCS	Wooden sprung court surface

Chapter 1

INTRODUCTION

1.1 INTRODUCTION

This thesis describes the scientific investigations undertaken as part of the sport science provision provided to the Great Britain Fencing Team, in the build up to the 2016 Olympic Games in Rio. These investigations were identified as fundamental to the development of a fencer's athleticism, in line with the demands of the sport, and were in turn identified by an initial literature review (Chapter 2), where current knowledge in this regard was critically appraised. The key techniques of a fencer, which are affected by athleticism, were found to be: 1) lunging, 2) change of direction speed (CODS) and 3) the ability to sustain these movements at maximal intensity throughout the duration of a competition. Given their significance, the physical characteristics that underpinned these were investigated in studies one and two (Chapters four and five respectively). It was also important to identify the physiological demands of competition, and the intensity of each bout, so that training zones and methods could be optimally designed. These would dictate fitness and conditioning based sessions and provide a means by which their efficacy could be gauged. Furthermore, because fencing competitions span an entire day, understanding within and post-competition fatigue was also crucial in the development of a periodised programme. Without this information, an appropriate training plan could not be devised, nor could its validity be judged. In response to these gaps in knowledge, the third study (Chapter six) monitored the fencing squad across two competitions and a fourth study (Chapter seven) analysed current training, including the appropriateness of training load, with respect to this. The nature of these two studies dictated additional detail be included in the literature review chapter. Here, strategies to monitor

training and competition load, fatigue and recovery were critiqued, enabling the use of appropriate methodology in these studies. Of note, a significant proportion of a fencers success is likely attributable to perceptual and psychomotor skills, namely the dexterous use of the sword and the rapid recognition and response of appropriate stimuli. These were considered outside the remit of sport science support and best developed through the sports coach and exposure to high level fencing competitions, as well as sparring with high-level opposition. Investigations here, and thus this thesis, centres on physical preparation.

In summary, it was hypothesized that the aforementioned investigations, formulated and guided by a critical review of research, would greatly benefit the physical preparation of Olympic fencers. The contents of the proposed studies including the literature review, which forms the basis of this thesis, are outlined below. Finally, this introductory chapter will conclude with a brief overview of the history of fencing and its transition from war-based duelling to sport; the text within this section is based on the work of Castle (2003) and Evangelista (1996). This is included to provide some background to what is largely regarded as a minority sport. This thesis also provides a general methods section (chapter three) to avoid between study repetition of protocols and for similar purposes, a general discussion section (chapter eight) where future research and study limitations are detailed.

1.2 STRUCTURE OF THESIS AND STUDY OUTLINES

Chapter 2, Literature Review.

Part one. Determinants of Success in Olympic Fencing

Fencing is one of only a few sports that have featured at every modern Olympic Games, but despite this, there is still much the sport science team does not know. Subsequently, and in contrary to many other sports, competition intensity is not well defined, the physical characteristics underpinning fundamental techniques require further investigation, and the appropriateness of fencing training programmes and the ability of these athletes to cope with and adapt to its demands is unknown. Such information is vital if sport scientists, including biomechanists, physiologists, psychologists and strength and conditioning coaches, are to appropriately address the needs of fencers. This review aims to undertake an analysis of the current literature to identify what is known, and questions that must be answered to optimise athlete support in this context. This review will also cover common injuries associated with fencing and how training may need to be adapted to also guard against these.

Part two. Developing Repeat Sprint Ability

Even cursory observational analysis will reveal the high intensity, intermittent nature of fencers and thus the demands for what is commonly referred to as repeat sprint ability; sprint in this context refers to any fast, high intensity action. Therefore this area required further analysis to appreciate the demands faced by athletes and how to measure this within fencers. This part of the review would start to uncover the predominant energy system used and the requirements for buffering capacity.

Part three. Monitoring Training Load, Fatigue and Recovery

Because studies three and four centred on the monitoring of training and competition in response to load, and the fencers ability to dissipate subsequent fatigue, these studies required a review of literature covering research within this context. This review aimed to identify the various strategies used to monitor load, fatigue and recovery, investigating the use of heart rate, blood lactate, ratings of perceived exertion, salivary analytes, jump tests and questionnaires. Following a critical review, appropriate methods were chosen and included in the subsequent studies.

Chapter 4, Study One. *Physical Characteristics underpinning lunging and change of direction speed.*

The aim of this study is to identify the physical characteristics that underpin both lunge and CODS performance, using tests that build on the aforementioned research. As such, the lunge will be determined using a force plate system that allows fencers to travel their "optimal" distance to strike a target. Reporting this with respect to time, i.e., lunge velocity, would normalize results for those that could lunge further but may take longer and vice versa. Also, a CODS test that replicates bout performance will be used, involving changes in direction required over short distances, coupled with a short overall distance and thus time to completion. Both test scores will be compared to anthropometric measures and dynamic measures of lower body power. Given the significance of front leg strength and lower-limb muscle imbalance, these will also be measured. On the basis of previous investigations, it is

hypothesized that both front and rear leg power would correlate to lunge and CODS performance, as would stature, arm-span and flexibility. Furthermore, it is predicted that the high impact forces during the landing phase of a lunge, would generate a lower-limb strength imbalance favouring the front leg.

Chapter 5, Study Two. *Physical Characteristics underpinning Repetitive lunging*

Given the repetitive demand to effectively execute lunging and CODS within each bout, the ability to sustain these at maximal capacity is likely to be fundamental to fencing performance. As yet this quality has not been reported on in the literature, and subsequently nor have the physical characteristics that underpin this feat of speed and power endurance. The first aim of this study therefore, is to report scores on this variable, referred to as repeat lunge ability (RLA), as well as identifying the physical characteristics that underpin its successful execution. Noting that associations from this would merely be theoretical, the second aim of this study was to identify if improvements in RLA could indeed be made if these characteristics were trained and subsequently improved. Because the utilised test involved lunging and CODS, it was hypothesised that similar associations to those identified in study one (chapter four) would be noted. Furthermore, given the demands of the test, which was designed to surpass the intensity of a fencing bout, it was also expected that an athlete's lactate tolerance and buffering capacity would affect their score.

Chapter 6, Study Three. *Competition Intensity and Fatigue*

As yet, no studies have looked to physiologically describe the effect of competition intensity and residual fatigue on biochemical and physiological responses, in order to inform training programme design. For example, measures of heart rate, blood lactate and ratings of perceived exertion taken within competition, can determine metabolic workload and the demands placed on the respective energy systems. Saliva analysis can reveal the (physical and emotional) stress of competition (and requirements for rest and recovery) by describing hormonal fluctuations in testosterone and cortisol, activation of the sympathetic nervous system through concentration changes in alpha amylase and any signs of adaptive immunity depression through reductions in immunoglobulin A. Finally, measures of stretch shortening cycle capability are considered indicative of neuromuscular fatigue. Collectively therefore, all measures are proposed to combine to describe competition demand and the requirements for recovery, affecting exercise selection and the programming and periodisation of these. The aim of this study therefore, is to use all aforementioned measures to describe these demands within a fencing competition, in order to inform training programme design.

Chapter 7, Study Four. *Monitoring Load, Fatigue and Intensity of Training*

The aim of this investigation was threefold. Firstly to describe the daily TL of the Great Britain Fencing team and how this impacted general performance indicators (jump scores and wellbeing); an analysis of this data, coupled with a "reflective" account, would help to establish the validity of this process along with its applicability to the elite-sport training environment. Secondly, was to compare conditioning sessions and competition data to check that intensity in the former was highest. Finally, how these sessions are best arranged within the training week, given the high fatigue that was hypothesised to be generated by them.

Anecdotal evidence led to the hypothesis that sparring in training, where athletes regularly face the same opponent and are not faced with the same "knock-out" pressure or win reward, would see training intensity less than competition intensity. Also, given previous research, training load would reduce morning measures (pre-training) of jump height and wellbeing.

1.3 THE HISTORY OF FENCING

The following section is included to provide the neutral reader with some background information on fencing, which is a relatively unknown sport. The information provided is based on the work of Castle (2003) and Evangelista (1996). Fencing was developed as the practice of swordsmanship to prepare men for duels and warfare. The earliest record of swordplay is found in a temple near Luxor, Egypt. The relief is suggested to describe a practice bout or match, as sword points are covered and swordsmen are wearing masks. Through generations, the sword has transitioned from a lightweight weapon to a crude heavier sword to combat the development of heavy body amour developed during the Middle Ages. Then, around the 14th century, the invention of gunpowder saw the sword became far less popular. Ironically, guns eventually made amour obsolete too, and the vulnerability of the now exposed body brought the sword back in to fashion as the only weapon that could be worn on the body for self-defence. Furthermore, it was now paramount that the swordsman learnt to skilfully weald the sword given this lack of protection.

Later, around the 16th century, the Italians discovered the effectiveness of the dexterous use of the point rather than the edge and so the much lighter rapier sword was born. Fencing now emphasized speed and skill, the lunge was established, and duelling centred on quick attacks, all the while keeping your opponent at distance. However, defence when duelling involved

either ducking or sidestepping, or the use of the left hand, which was protected by a gauntlet or cloak, or carried a dagger. Finally in the 17th century, and attributed to a change in gentlemen's dress (with the notable absence of the gauntlet and cloak), the French took fencing through its final transition and in to what we recognize it as today. The sword again became lighter and adapted to be suitable to be used in defence and thus as the sole weapon of combat; swordsman were educated to use the edges of the blade in this regard. Emphasis was now firmly on form and strategy. In the development of technique, the practice sword or foil was developed and facemasks warn; schools or "salles" were formed along with rules to regulate practice. During the 18th century, when fencing reached its peak in terms of technique and theory, the sword again became obsolete given the growing accuracy of firearms. From this point on, fencing took on the role of a sport. Over the years and in to the 19th century, the epee and sabre were also added as additional swords; the latter devised by the Hungarians (and then modified by the Italians) for use with their Calvary.

Fencing featured on the programme of Games at the first ever Olympics in Athens, 1896; it has been at every Olympics since. At first, the games just featured the foil and sabre, with epee included in 1900. Women competed for the first time at the VIII Olympiad in Paris, 1924. At first, this only included foil with epee and sabre joining later at the 1996 Games in Atlanta and the 2004 Games in Athens respectively. Given the various arguments of rules and regulations that challenged the early games, the Federation Internationale d'Escrime was founded in 1913 as the governing body of international fencing for amateurs. As one may expect from its history, fencing competitions have been mainly dominated by the Italians and French, and also the Hungarians in Sabre. That is, up until now of course…

Chapter 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will review pertinent areas for optimal physical preparation in fencing. In doing so, the literature will be divided in to three parts to facilitate the grouping of key themes. The first review (part one) will assess all available literature regarding the physicality of fencing, looking at data within performance analysis, fitness testing, injury prevention and analysis of movement (i.e., kinetics and kinematics). The second part will focus on repeat sprint ability, noting that sprint in this context can be used interchangeably with all high intensity type movements. Given the requirements for athletes to engage in repeated high intensity efforts, a greater understanding of this area was warranted. Finally, in part three, a critical review of monitoring tools for training load, fatigue and recovery will be investigated so that appropriate methodologies can be used in future studies. Only pertinent resources will be examined noting that more popular tools for the external monitoring of training load, such as global positioning system, are not applicable.

2.2 METHODS

A structured electronic search of all publication years (through April 2014) using PubMed, SPORTDiscus and Summon was conducted. For the fencing specific component of this review, the following search strings were used: “fencing”, “foil”, “sabre”, “epee”, “lunge” and “fleche”. Given the paucity of research within fencing, such broad terms could be used.

Using the abstracts, studies that focused only on cognition and reaction time were excluded, with the remaining grouped based on the following themes: performance analysis, fitness testing, injury prevention, performance physiology and analysis of movement (i.e., kinetics and kinematics). Finally, using the full-text articles, reference lists were checked for additional suitable research.

For the monitoring training part of this review, a literature search was again conducted using PubMed, SPORTDiscus and Summon (publication years through April 2014). The following search terms were used: "training load OR impulse", "heart rate AND recovery OR variability", "Questionnaire AND Fatigue", "Endocrine AND testosterone OR cortisol OR IgA OR alpha amylase". Articles were rejected if abstracts did not show relevance to healthy athletes, training or competition. Also, given the volume and advancements in assessment, research papers were limited to those published in the last 10 years. Finally, using the full-text articles, reference lists were checked for additional suitable research; here older research (> 10 years) was included if deemed appropriate.

2.3 PART ONE. DETERMINANTS OF SUCCESS IN OLYMPIC FENCING

Fencing is one of only a few sports that have featured at every modern Olympic Games. Fencing takes place on a 14 x 2 m strip called a 'piste', with all scoring judged electronically due to the high pace of competition. The winner is the first fencer to score 5 hits during the preliminary pool bouts or 15 hits should they reach the direct elimination bouts. During the preliminary pools, bouts last three minutes, while during elimination, each bout consists of three rounds of three minutes, with one-minute rest between rounds (FIE, 2014). In general, fencing involves a series of explosive attacks, spaced by low-intensity movements and recovery periods, predominately taxing anaerobic metabolism

(Wylde, Frankie, & O'Donoghue, 2013; Guilhem, Giroux, Chollet, & Rabita, 2014). Perceptual and psychomotor skills (i.e., the ability to quickly and appropriately respond to an opponent's actions) prevail, and there is a great need to repeatedly defend and attack, and often, engage in a seamless transition between the two. There are three types of weapon used in Olympic fencing; these are the foil, epee and sabre. In foil fencing, scoring is restricted to the torso, in epee the entire body may be targeted and in sabre, only hits above the waist count (FIE, 2014).

In order for sport science and the practitioners of its sub-disciplines (e.g., biomechanics, physiology and strength and conditioning) to support these athletes, a review of this sport must first be undertaken, addressing the available scientific research and synthesizing evidence based on competition demands and athlete physical characteristics. Such an analysis will help the sport science team in identifying the key components that lead to successful performance and address any pertinent questions that remain unanswered. This chapter aims to undertake this review and in doing so, describe competition demands according to four subsections: (1) time motion analysis, (2) physiology, (3) biomechanics and (4) incidence of injury. Athlete physical characteristics will subsequently be addressed along with suggested testing protocols and training exercises. This chapter will conclude by identifying areas for future research, thus forming the bases of studies comprising of this PhD thesis.

2.4 TIME-MOTION ANALYSIS OF ELITE FENCERS

Fencing tournaments take place over an entire day (often lasting around 10 hours) and consist of around 10 bouts with a break of anywhere between 15-300 minutes between each bout

(Roi & Bianchedi, 2008). Rio & Bianchedi (2008) have reported the time-motion analysis (TMA) data of the winners of the men's and women's epee and men's foil at an international competition. In general, results reveal that bouts and actual fight time consist of only 13 and 5% of actual competition time respectively, with a bout work : rest ratio (W : R) of 1:1 and 2:1 in men's and women's epee respectively and 1:3 in men's foil. On average, a foil fencer will work for 5 s while an epee fencer will work for 15 s (much of which is sub-maximal) before each rest period or interruption. Furthermore, during each bout, a fencer may cover between 250-1000 m, attack 140 times and change direction nearly 400 times in women's epee and around 170 times in men's epee and foil. Also, Roi and Pittaluga (1997) reported a significantly greater number of directional changes when comparing female fencers of high and low technical ability (133 ± 62 *vs.* 85 ± 25 respectively, $p < 0.05$), suggestive of different tactical levels.

Wylde, Frankie, & O'Donoghue (2013) also examined TMA data during competitive bouts of elite women's foilests and found a W : R of 1:1.1. They further investigated the differences between 15 hit, 5 hit and team bouts with respect to time spent engaged in low (e.g., stationary or walking), moderate (e.g., bouncing, stepping forward/backwards) and high (e.g., explosive attacking or defensive movements) intensity movements. Differences were analysed using magnitude-based Cohen's (Cohen, 1988) effect size (ES) with modified qualitative descriptors (Hopkins W. , 2002) as follows: < 0.20 = trivial, 0.20 to 0.60 = small, > 0.60 to 1.20 = moderate, > 1.20 to 2.00 = large, and > 2.00 = very large. They found that high-intensity movements accounted for 6.2 ± 2.5% of total bout time with a mean duration of 0.7 ± 0.1 s and a mean recovery period of 10.4 ± 3.3 s. The only "large" difference between the bouts was found for the greater mean duration of the low-intensity movements in the 15 hit bouts (6.1 s *vs.* 4.5 s; of note this included the rest periods not available in the others). All other differences were "moderate", "small" or "trivial". They therefore suggested

that similar training plans could be used to physically prepare fencers for 15 hit, 5 hit and team bouts.

Finally, sabre has been the subject of TMA (Aquili & Tancredi, 2013), in which 32 men and 25 women were analysed during elimination bouts across world cup competitions. Results reveal its "explosive" reputation is possible due to short bouts of action of ~2.5 s, interspersed with longer recovery periods of ~15 s, producing a W : R of ~1:6. On average, there are 21 lunges, 7 changes in direction and 14 attacks per bout. Total bout time rarely exceeded 9 min (including between round breaks), with only ~70 s of this regarded as fight time.

In summary, and noting that relative to other sports the available TMA is scarce, the W : R of each sword differs (1 : 1 in epee, 1 : 3 in foil and 1 : 6 in sabre), with sabre seeming to be almost entirely driven by anaerobic power production. While epee (although much of which is submaximal) has longer fight times than foil and sabre (15, 5 and 2.5 s respectively), it appears that each weapon is still provided with sufficient recovery to work at high intensities throughout each bout. For example, within round rest periods appear to be ~15 s regardless of sword and bouts rarely last the allotted time, with only ~ 5% of a bout in foil and epee, and 70 s in sabre, actually spent "fighting". Perhaps the most physically demanding aspects of the bout are incurred when changing direction and attacking using a lunge (and the recovery from this), which is a frequent occurrence; indeed, the ability to quickly and efficiently utilise the lunge may be indicative of success (Roi & Pittaluga, 1997). Therefore, regarding programme design, there is a clear need to develop change of direction speed (CODS), lunge speed and the ability to employ these over a possible 3 rounds of 3 min. It is therefore inferred that fencing is a predominately anaerobic sport and that "explosive" movements define performance. Such conclusions advocate strength and power training (and their assessment) for the development of speed and the use of high intensity interval training (HIIT; using

weapon specific W : R) to contend with the repeated execution of these skills.

Furthermore, given the continuous employment of CODS and lunging, a high incidence of muscle damage across a tournament is likely, largely exacerbated by the plethora of eccentric contractions (Raastad, et al., 2010) generated during the lead leg foot strike of the latter (Figure 2.1) although currently not quantified, this is likely to be substantial. Because muscle damage reduces maximal voluntary contraction force (Raastad, et al., 2010) and therefore related functions such as jump height (Miyama & Nosaka, 2004), it is likely that the efficacy of each lunge will gradually reduce. As such, it is recommended that fencers be subjected to high eccentric loads as part of their strength and conditioning (S&C) programme; muscles accustomed to eccentric loading show greater resistance to muscle damage than those which are not (Newton, Morgan, Sacco, Chapman, & Nosaka, 2008). While it is possible for the muscle to adapt to eccentric loads by virtue of the "repeat bout effect" phenomenon alone (McHugh, 2003; Clarkson, Nosaka, & Braun, 1992), this adaptation will be facilitated by resistance training where it is possible to expose athletes to loads in excess of that experienced during training or competition. For example, training the eccentric phase of exercises (e.g., using loads in excess of the concentric one repetition maximum [1RM]) and emphasising the landing components of Olympic lifts and plyometrics. Therefore these should be used in conjunction with HIIT to further facilitate the continuous high-speed execution of CODS and lunging.

2.5 PHYSIOLOGICAL DEMANDS OF FENCING

Only Milia et al., (2014) have looked at the physiological responses during competitive fencing. They tested 15 skilled fencers (2 female, 13 male; group is representative of mid-upper level fencers) that regularly participated in competitions over the last 4 years. In

comparison to a preliminary incremental maximum oxygen uptake ($\dot{V}O_2max$) test (in which they reported low values for aerobic capacity: 46.3 ± 5.2 mL/min/kg), they found that a simulated 3 x 3 min bout (while wearing a portable metabolic system) only moderately recruited aerobic energy sources, with oxygen consumption ($\dot{V}O_2$) and heart rate (HR) remaining below the anaerobic threshold (AT); the AT was recorded at 78% of $\dot{V}O_2max$. Similar patterns were observed for pulmonary ventilation and the rate of elimination of carbon dioxide ($\dot{V}CO_2$), again suggesting that fencing only imposed moderate respiratory and metabolic stress. Of note, they found that despite athletes performing below the level of AT, lactic anaerobic capacity was moderately activated to support the energy requirements of the combat rounds, with blood lactate remaining > 6 mmol/L throughout (and peaking at 6.9 mmol/L). They attributed this to the much greater use of the arms during combat compared to the incremental test used to assess AT, and the arms greater composition of fast-twitch fibers compared to the legs. This was considered a better indication of fencing's anaerobic energy demand and is similar to that of Cerizza and Roi (1994), where blood lactate concentrations of men's foil fencing bouts (measured 5 minutes post bout) were quantified. Scores averaged 2.5 mmol/L during the preliminary bouts and were then consistently above 4 mmol/L (and as high as 15.3 mmol/L in the winner) during the elimination bouts. Furthermore, across three practice 5 hit sparring bouts (thus simulating the pools) against different opponents, national and international level epee and foil fencers (13 female and 15 male, average age of 16.8 years) had an average blood lactate concentration of 1.7 mmol/L and heart rates were between 120 and 194 bpm. Again (when considering W : R and actual fight times reported above) this data reveals fencing's anaerobic dominance but specifically, identifies that the pools (5 hits) predominately derive energy from the alactic system while the elimination rounds (15 hits) from the lactic acid system.

Similar to Milia *et al.,* (2014), Rio & Bianchedi (2008) also reported that while the average aerobic capacity of fencers (52.9 mL/kg/min) is greater than that of the sedentary population (42.5 mL/kg/min) it is clearly lower than that of aerobic endurance based athletes (e.g., 62 - 74 and 60 - 85 mL/kg/min in long distance cyclists and runners respectively) (Wilmore & Costill, 2004) and again may be suggestive of the relatively small role a high (> 60 ml/kg/min) $\dot{V}O_2$max has to fencing. To gain further insight, and because of the little (direct) data available in fencing, it may be prudent to look at the indicative results of empirically similar sports (given their intermittent, explosive nature) such as wrestling, boxing and mixed martial arts (MMA); even basketball and ice hockey may hold merit. All are considered as anaerobic sports, with the primary energy system for the first two considered to be the phosphagen system, followed by anaerobic glycolysis, while the others consider them of equal importance (Ratmess, 2008). When interpreting this data, it is important to note that rounds are fewer than boxing (3 *vs.* 12) and shorter than both wrestling and MMA (3 *vs.* 5 min). Of course, while basketball and ice hockey share a similar intermittent nature, they occur over a longer duration and incur fewer interruptions to play. Collectively, a case may be built to suggest that aerobic energy system contribution may be relatively small and predominately involved in the sub-maximal movements of the on guard position and during recovery periods (inter- and intra-bout). Also, while the energy system requirements of each weapon will inevitably differ, it may be that none will significantly tax the aerobic system to the extent that training need directly target its development; this will instead be indirectly developed by virtue of (more sport specific) HIIT (Helgerud, Hoydal, Wang, Karlsen, Berg, & Bjerkaas, 2007). Of note, while the aerobic system facilitates recovery from high-intensity exercise, enabling the athlete to perform subsequent bouts in quick session, only moderate values (e.g., 50-60 ml/kg/min) are required, with values above this not translating to quicker recovery times (Hoffman, 1997). Similar findings have been identified in ice hockey (Carey,

Drake, Pliego, & Raymond, 2007) and basketball (Hoffman, Tenenbaum, Maresh, & Kraemer, 1996). Furthermore, the review of Elliott *et al.,* (2008) described how long slow distance running (the traditional form of aerobic training) in contrast to HIIT is detrimental to strength and power output (which appear critical for lunging and CODS) and their development.

In summary, it appears that the pool bouts rely more on the alactic system (and therefore phosphocreatine as fuel) while the elimination bouts rely more on the lactate system (and therefore glucose as fuel). Currently data is not available for sabre but following what is reported herein, sabre is likely to predominately tax the alactic system across both types of bout. Finally, while a fencer may compete over an entire day and face several bouts, the majority of this time is spent resting (~87%), therefore, recovery interventions such as cool-downs, hydration and nutrition and those that affect thermoregulation, are likely to prove beneficial (although a discussion of these is beyond the scope of this chapter) and anecdotally, are often overlooked. It is a common misconception that a high aerobic capacity will fend off fatigue across the long days that make up fencing competitions; only 10% of competition time is active and of that, actions are considered short with ample rest between each. It should also be noted that Milia *et al.,* (2014) found that none of the studied variables (HR or blood lactate) returned to resting levels during the 3 min of final recovery and concluded that athletes need to use specific training programs able to improve this ability. Coupled with the TMA data presented above, data again supports a HIIT approach for fencers, as in addition to being specific to the "stop-start" and explosive nature of fencing, it can be manipulated to evoke high blood lactate responses, while challenging and thus adapting the recovery process, including decreasing the accumulation of, and increasing the tolerance to, hydrogen ions (Baker, 2011) – this is discussed further in part two of this review (section 2.10).

2.6 BIOMECHANICAL ANALYSIS OF FENCING

2.6.1 The 'On Guard' Position

Fencing utilises an "on guard" position (Figure 2.1) in which the fencer "bounces" in preparation for attack. This position enables a rapid manipulation of the base of support and therefore the centre of mass, whereby the fencer can quickly transition from attack to defence and vice-versa. This ability is fundamental as in order to cope with an opponent's feint (or indeed attack), a fencer must be able to quickly transition from a current or intended action to a new one which can accommodate this. While this is determined largely by perceptual and psychomotor skills, a fencer must have the physical requisites to capitalise on this. Given the bounce, semi-squat position and rapid response required, a logical inference is to suggest exercises that train rate of force development and plyometric ability would be beneficial. While the on guard position is yet to be examined, the attacking lunge has, and is described below.

2.6.2 The Lunge

By far, the lunge (Figure 2.1) is the most common form of attack, with others including those derived from in-stance counter-attacks (following a parry for example) and the fleche (Figure 2.2). Furthermore, with around 140 attacks per competition and around 21 per bout, the significance of the lunge and the need to optimally execute this repeatedly is clear. Cronin *et al.,* (2003) have addressed the lunge performance and its determinants, and although not specific to fencing, there is likely some applicable transfer. Here, maximal strength and power of the preferred leg was measured on a supine squat machine; the latter was against a resistance of 50% 1RM. These were tested against lunging performance assessed via a linear transducer (data sampled at 200 Hz) attached to a belt, strapped to the trunk. The 31 male

recreational athletes had to lunge to a cone (1.5 times their leg distance) and back as rapidly as possible; the maximum velocities recorded were 1.64 and 1.68 m/s respectively. It was found that time to peak force (TPF) was the best single predictor of lunge performance (velocity out to the cone; r = 0.74), which accounted for 54% of the explained variance. The best three-variable model for predicting lunge performance was TPF, leg length and flexibility (measured as the linear distance between the lateral malleolus of each leg during a split in the frontal plane), accounting for 85% of the explained variance. The investigators concluded that lunging performance was based on several physical and anthropometrical measures, which should form part of an athlete's fitness testing battery.

Figure 2.1 The lunge (right to left), commencing from the on guard position

Gholipour, Tabrizi, & Farahmand, (2008) cinematically analysed the fencing lunge in elite and novice fencers. Using three cameras (recording at 50 frames per second [fps]), it was revealed that the elite group lunged further (1.17 m *vs.* 1.02 m) although slower (1.82 s *vs.* 1.46 s), the lead leg knee had less initial flexion (20 deg *vs.* 38 deg) but greater mid phase extension (51 deg *vs.* 18 deg), exhibited greater hip flexion in the final stage of the lunge (53 deg *vs.* 40 deg) and contrary to popular belief, the armed hand and leg moved simultaneously (as opposed to the former preceding the latter). In contrast, Gutierrez-Davila *et al.,* (2011) examined (using 3D video analysis recording at 500 Hz) elite *vs.* medium level fencers while lunging and reported an average movement time of 601 ms *vs.* 585 ms respectively (here

timing was stopped when target contact was made), but the former again covered a significantly ($p < 0.001$) greater distance of 1.4 m *vs.* 1.13 m. Interestingly, the flight phase of the lead foot in elite fencers represented 36 ms, the rest was regarded as the acceleration phase, whereby the force required to lunge was generated. Also, this group, unlike the medium level comparison group which made a simultaneous forward movement of the foot and sword arm, executed a temporal arm-foot sequence. As a result, the elite were quicker to reach maximum velocity in the initial extension of the arm (31% *vs.* 45% of total movement time) and average sword horizontal velocity (4.56 m/s *vs.* 3.59 m/s), subsequently achieving maximum horizontal velocity of the foot later (75% *vs.* 58%). They suggested that results highlight the importance of starting the advance with a rapid thrust of the arm, followed by a lunge forward with the lead foot. The temporal arm-foot sequence is required for correct technique and also determines the right of way (priority) in foil and sabre competitions. According to the international federation of fencing (FIE, 2014) the rules state that: *"the attack is the initial offensive action made by extending the arm and continuously threatening the opponents target, preceding the launching of the lunge or fleche"*. In summary, while the arm-foot sequence contradicts the well-accepted "ground up" based kinematics of most sports e.g., baseball (Oliver & Keeley, 2010), javelin (Whiting, Gregor, & Halushka, 1991) and tennis (Johnson & McHugh, 2006), priority ruling dictates this. As such, fencers must be trained to quickly extend their arms independent of force generated at the legs, and thus supports the use of strength and power training targeting the upper body.

Stewart and Koetka (2005), noting an arm-foot sequence, found the only kinematic variable demonstrating a significant relationship to lunge speed was the maximum angular velocity at the elbow ($r = 0.62$). They also found that the overall speed of the lunge is not as dependent on how fast the maximum angular velocities of the lead elbow and knees are, as how soon these maximum velocities can be reached; similar to Cronin *et al.,* (2003) the training of rate

of force development appears fundamental. These investigators also measured speed using a camera collecting data at 50 Hz. However, low frequency data collection such as this (error rate ± 20 ms) may be unable to distinguish between levels of athlete. For example, Tsolakis *et al.,* (2010) found a significant difference in lunge time of only 30 ms (measured at 250 Hz) between elite and sub-elite fencers; this may not have been detected at 50 Hz. Also (as aforementioned) the flight phase of the lead foot represented 36 ms, this again may be too short a variable to measure at low frequencies. While more data is required to determine lunge time, speed and movement mechanics, it may be prudent to collect this at frequencies above 50 Hz.

Quantitative data describing the kinetics of the lunge, with respect to push-off and landing forces, has only been determined by Guilhem *et al.,* (2014). They used a 6.6 m-long force plate system where elite female sabreurs (French national team; N = 10) performed a lunge preceded by a step. From this, displacement and velocity was calculated and compared to dynamometry strength testing of the hip and knee. The fencers' centre of mass travelled 1.49 m in 1.42 s and at a peak velocity of 2.6 m/s, generating a peak force of 496.6 N, with maximal negative (braking) power at front foot landing equalling 1446 W. Maximal velocity was significantly ($p < 0.05$) correlated to the concentric peak torque produced by the rear hip ($r = 0.60$) and knee ($r = 0.79$) extensor muscles, as well as to the front knee extensors ($r = 0.81$). Also, through EMG analysis, they showed that the activation of rear leg extensor muscles i.e., gluteus maximus, vastis lateralis and soleus, was correlated to LV ($r = 0.70$, 0.59 and 0.44 respectively). Collectively their findings illustrate that the ability to move forward and to decelerate the body mass as quickly as possible is a fundamental performance determinant of fencing and supports the use of strength training as previously suggested.

Finally, Gresham-Fiegel *et al.,* (2013) analysed the effect of non-Leading foot placement on power and velocity in the fencing lunge (the swords used were not defined). While the toes of the leading foot generally point directly toward the opponent, the angle of the back foot may vary greatly among fencers, from acute (facing forward) to obtuse (facing slightly backward). In their study, experienced fencers executed lunges from three specific angles of back foot placement as well as from the natural stance. Foot placements were measured as the angle of the back foot from the line of the lead foot and were delimited to an acute angle (45 deg), a perpendicular angle (90 deg), and an obtuse angle (135 deg). The angle of natural stance was also determined (which ranged 68-100 deg) and assessed for each participant. Velocity and power were measured with a linear transducer (recording at 200 Hz) revealing that a perpendicular placement of the foot produced significantly ($p < 0.05$) greater power (peak = 849 W; average = 430 W) and velocity (peak = 1.21 m/s; average = 0.61 m/s) during lunging.

In summary, the lunge dictates the need for both concentric and eccentric strength. The back leg must drive/accelerate the body over almost 600 ms (Gutierrez-Davila, 2011) before the lead leg can leave the ground and travel around 1.4 m. Greater concentric strength of the back leg, and the rate with which this is developed, will enable quicker and/or longer attacks. Because it is generally desirable to keep the back foot in contact with the ground, and perpendicular to the plane of attack, extension at the ankle is limited, so knee and hip extensor force may be most important. Lead leg knee flexors (namely the hamstrings) must then control rapid knee extension during the flight phase to enable high angular velocities at the knee and reduce the likelihood of injury; the high incidence of hamstring strains in these athletes (discussed below) may be indicative of the need to target these muscles. Finally, the front knee extensors must exert high braking forces at landing; the eccentric forces experienced by the lead leg are likely to be high and may be evidenced by the greater thigh cross-sectional area of the lead *vs.* back leg (213.45 vs 208.22 cm^2) (Tsolakis & Vagenas,

2010). The ability to quickly arrest this forward momentum, i.e., reduce the required knee flexion, may reduce the transition time to change direction and return to on guard. This would decrease the time the opponent has to counter attack should the lunge be unsuccessful. Considering there are 21 lunges per bout, it is clear that not all lunges are successful. In fact, there is more chance of missing than scoring, thus recovery mechanics are an important component. Lead foot contact time, although dependent on surface and shoe type, lasts ~700 ms (Trautmann, Martinelli, & Rosenbaum, 2011), and (excluding surface and footwear) may be a function of eccentric strength in the quadriceps, as landing is made with the heel thus minimising contribution from the muscles of the ankle.

While eccentric strength has only been indirectly assessed via reactive strength index (discussed below), maximum strength and power have received more attention with TPF (albeit in lunges common to racket sports) and squat and countermovement jumps (discussed below) identified as strong predictors. The strong correlation between strength and power tasks (r = 0.77- 0.94) (Asci & Acikada, 2007), and the additional time over which a lunge is executed compared to the majority of other sports motor skills (e.g., 600 ms *vs.* ≤ 300 ms (Zatsiorsky, 2003) should see maximum strength take higher precedence in the lunge. Finally, as this movement is initiated via a pre-stretch of the back leg, it also utilises the stretch-shortening cycle (SSC) and thus this also needs to be targeted. For example, Tsolakis *et al.,* (2010) reported that continuous fencing steps with rhythmic changes in direction are activated by SSC's, which in turn influences the subsequent propulsive concentric muscle contraction of the following lunge. More research describing the kinetics and kinematics with the lunge is required. Arguably the speed (time to target) and range of lunge and thus their derivate, lunge velocity, are most important; determining how athletes optimise these may be key. More data is required to see the contribution made from strength, power, flexibility and stature attributes of the athlete. Data should also represent the ability to recover from a

missed lunge and lunges made from a “flying” start (i.e., preceded with a change of direction or forward steps).

Currently, data again suggests the use of strength (including eccentric) training coupled with plyometric and ballistic type exercises to reduce ground contact times and enhance the rate of force development respectively. Squats and deadlifts appear good exercise choices (particularly the latter) as they target the knee and hip extensors, also bench press and seated medicine ball throws for example, as they target upper body strength and power development respectively. The development of reactive strength (and thus reduced ground contact times) coupled with “deep” squats (below parallel) or split squat exercises can help target the gluteal muscles and collectively train a fast recovery from the lunge back to on guard. Given the prolonged ground contact times (~700 ms) and flat-footed front leg drive (i.e., not involving ankle extension), hip and knee extensor strength may take on added importance here. Finally, Nordics and stiff leg deadlifts can help reduce the high incidence of hamstring strains and increasing adductor flexibility may enhance (or at least not limit) lunge distance.

2.6.3 The Fleche

The fleche (not applicable to sabre; Figure 2.2) is perhaps best described as a “running” attack. Again, like the on guard position, little data is currently available but as coached, requires that from the on guard position, the back leg is forcefully brought in advance of the lead leg in such a way that the foot of the back leg steps over the opposite knee. Due to the high momentum of the movement, the fencer is unable to stabilise their position at landing and will thus bring the movement to a halt following a “run”. Furthermore, the fencer aims to strike the opponent before landing, so the final sequences of the fleche represent deceleration

phases. The physical requirements of this movement are expected to be similar to that of the lunge.

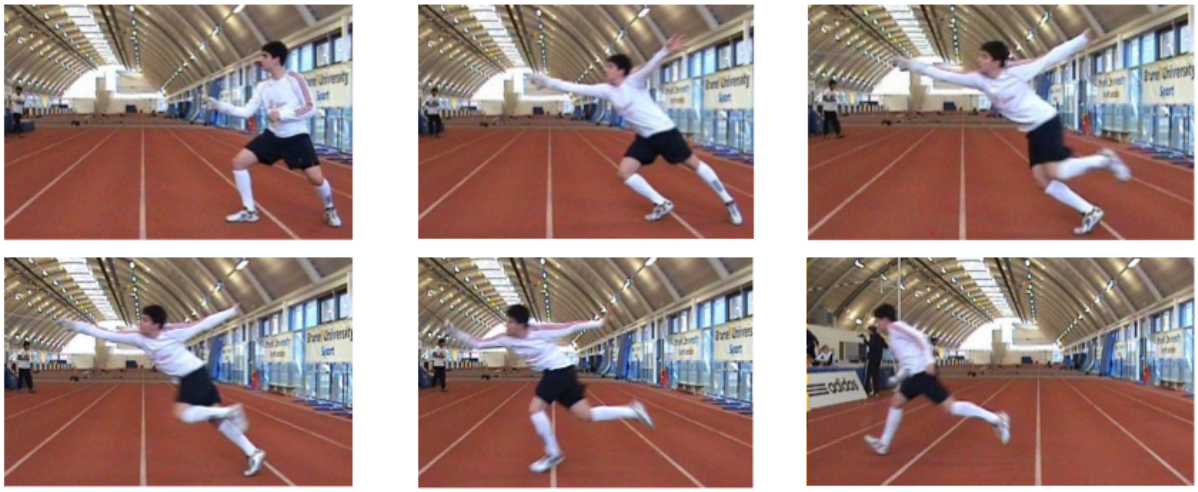

Figure 2.2 The fleche (left to right, top to bottom) is initiated from a lunge position whereby the back leg is powerfully driven forward of the lead leg. The hit would have been made before the lead foot hits the ground again, but the body continues forward due to the high momentum.

Frere *et al.,* (Frere, Gopfert, & Nuesh, 2011) provide a kinematical analysis of the fleche, analysed at 240 Hz in 8 male expert fencers. The group was split into an early (n = 4) and late maximal elbow extension group. The former presented two peaks in horizontal velocity; one of the weapon hand and the other as the body leans forward into the attack phase. The latter group produced only one peak, which they described as optimal, despite it not conforming to the rules (as aforementioned). The group that simultaneously extends their arm and lunges forward removes the delay between velocities, thus allowing the fencer to hide the type of attack. As described above however, this will not grant the fencer priority and reduces maximal elbow angular velocity and horizontal and vertical velocity of the hand (656 vs 430°/s; 1.88 *vs.* 1.47 m/s; 2.07 *vs.* 1.57 m/s respectively); it appears there are pros and cons for each.

Unlike the lunge, TMA data describing the frequency of the fleche and its success rate is not published. The assumption from this is that the lunge is used to a far greater extent and thus sport scientists must first address this movement before using resources to better determine and optimise fleche mechanics.

2.7 RISK OF INJURY

Perhaps the most insightful research project to investigate injuries in fencing was conducted by Harmer (2008), who collected data from all national events organised by the U.S. Fencing association over a 5 year period (2001-2006). In total, over 78,000 fencers (both genders), from 8-70 years of age and across all weapons were investigated. Throughout this period, all incidents that resulted in withdrawal from competition (i.e., a time-loss injury) were documented from which the incidence and characteristics of injuries were calculated. This value was determined as the rate of time-loss injuries (TLI) per 1000 hours of athlete exposures (AE), with one AE equalling one bout. There were 184 TLI in total, at a rate of 0.3/1000 AE. The TLI of foil and epee was similar and highest in sabre (0.26 vs, 0.42/1000 AE). Strains and sprains accounted for half of all injuries and contusions for 12%. The lower extremities accounted for most injuries (63%) and mostly involved the knee (20%), thigh (15%, three quarters of which were hamstring strains) and ankle (13%). Finally, above the hip, TLI of the lumbar spine (9%) and fingers (7%) predominated.

Harmer (2008) concluded that the risk of injury in fencing is very low with the chance of injury in football and basketball 50 and 31 times greater respectively. When injury does occur, it is most likely to occur at the knee, hamstring strains are the most common type of injury and male sabreurs are most at risk. Because fencers tend to use (and therefore develop) the anterior musculature more than the posterior, and one side of the body more than the

other, this may leave them exposed to muscle strains in the weaker muscles (as exampled by the higher incidence of hamstring to quadriceps strains). More specifically, Guilhem *et al.,* (2014) warn that repetitions of the lunge or maintaining the on guard position over prolonged periods may cause pathologies such as the adductor compartment syndrome and the compression of arteries in the iliac area due to hypertrophy of the psoas major (Cockett syndrome), or induce osteoarthritis. A difference of >15% is generally used as a clinical marker of bilateral strength asymmetry and significant risk of injury (Impellizzeri, Rampinni, & Marcora, 2007). Strength training may be able to address this imbalance as well as increasing antagonist muscle strength. Pertinent to performance, an increase in antagonist muscle strength may increase movement speed and accuracy of movement (Jaric, Ropert, Kukolj, & Ilic, 1995). This has been hypothesised to occur due to alterations in neural firing patterns, leading to a decrease in the braking times and accuracy of the limbs in rapid ballistic movements (Jaric, Ropert, Kukolj, & Ilic, 1995). In essence, strength balance is also needed to break the agonists succinctly in rapid limb movements and as such, increases in hamstring strength will enable faster velocities of knee extension. Of course, strength training will also enable the weaker limb (typically the back leg) to be targeted.

Recently, research has investigated foot strike characteristics and injurious potential; epidemiological investigations propose a positive relationship between impact shock magnitude, rate of repetition, and the aetiology of overuse injuries (Nigg & Segesser, 1992; Pohl, Mullineaux, Milner, Hamill, & Davis, 2008). Trautmann *et al.,* (Trautmann, Martinelli, & Rosenbaum, 2011) used pressure insoles, covering the whole plantar aspect, to collect plantar pressure data (sampled at 50 Hz) of the lunge performed with three different shoe models: the athletes' own fencing shoes (used for training and competition), Ballestra (Nike, Beaverton, OR, USA) and Adistar (Adidas, Herzogen- aurach, Germany). Results showed higher peak pressures at the heel compared to the midfoot, forefoot, hallux and the toes

(551.8 *vs.* 156.3, 205.4, 255.6 and 170.4 kPa respectively). The heel also had the highest impulse (179.2 Nm; followed by the forefoot: 175.6 Nm) and contact time (705.4 ms). The new shoes (Adistar and Ballestra) were able to significantly ($p < 0.005$) attenuate impact pressure more than the fencer's own shoe, but this may have been a consequence of wear. Subsequently, shoe-cushioning characteristics should be considered as an extrinsic risk factor for overloading of the lower limbs, with meniscal and chondral lesions of the knee considered as an expression of such repetitive tasks. Harmer (2008) suggested teaching athletes to check insole wear and to maintain good quality insoles, and Trautmann *et al.,* (2011) advised that improved cushioning beneath the heel and metatarsal heads could be advantageous in preventing an injury during competition or training. In addition, fencers should be limited in performing high-demand tasks, especially the lunge, during recovery from an injury (Trautmann, Martinelli, & Rosenbaum, 2011).

Greenhalgh *et al.,* (2013) carried out a similar study but here the dependent variable was training surface: concrete with an overlaid vinyl layer (COVL); wooden sprung court surface (WSCS); metallic carpet fencing piste overlaid on the WSCS and; aluminium fencing piste overlaid on the WSCS. An accelerometer measured accelerations along the longitudinal axis of the tibia at 1000 Hz. Results identified a significantly ($p < 0.05$) larger impact shock was experienced during a lunge on the COVL (14.88 ± 8.45 g) compared to the others (which averaged ~ 11.6 g). Furthermore, the two types of piste used had no significant effect on the impact shock when overlaid on the WSCS compared to the WSCS on its own. Results suggest that injuries related to impact shock may be reduced using a WSCS rather than a COVL surface, during fencing participation.

The data above again describes the need to develop hamstring strength and warns of the overuse injuries generated subsequent to continuous fencing in an asymmetrical stance (see Figure 2.1), which never alternates. Consequently, it would be prudent to include training that

puts high landing loads through the back foot (thus training the weaker limb) and exercises such as the split jerk and split snatch (here the stance is reversed), which similarly have flat, front-foot landings, are advised. Of course, single leg jumps favouring this side would be advantageous too. When performing HIIT (as advised above) it may be advisable to not use, or at least limit the use of fencing footwork in their orthodox stance. Instead, either their stance can be switched or use non- or reduced weight-bearing activities. While this is less sport-specific, ultimately the W : R ratios can still be used to evoke high blood lactate response and invoke adaptions centring on the tolerance and recovery from continuous explosive exercise. Finally, the use of the various squat and deadlift exercise, in addition to reduced training exposure to their fencing stance, should facilitate the reduction of lower back pain.

2.8 PHYSICAL CHARACTERISTICS

Tsolakis and Vagenas (2010) examined differences in selected anthropometric, strength-power parameters and functional characteristics of elite and sub-elite fencers. Thirty-three fencers (18 females and 15 males) from the Greek National Team (age 19 ± 3.5 yr, body height 175.6 ± 7.6 cm, body mass 66.1 ± 9.1 kg, systematic training 8.4 ± 2.9 yr) were classified as elite (n = 14, each having competed in the Olympic games and/or World championships) or sub-elite according to their international experience. Compared to sub-elites, elite fencers are taller (178 *vs.* 173 cm), leaner (13 *vs.* 16% body fat), have a higher squat jump (31.94 *vs.* 25.74 cm), countermovement jump (35.47 *vs.* 31.04 cm) and reactive strength index from a 40 cm box (1.48 *vs.* 1.38). They also compared lunge time and shuttle test scores, where again elite athletes performed better (180 *vs.* 210 ms and 12.43 *vs.* 13.28 s respectively). Time of lunge was measured via four photocells (measuring at 250 Hz) placed

at a lunge distance of 2/3-leg length, with the height of the photocells adjusted to be interrupted by the chest. This setup indicates why results are markedly different from what is reported above, thus making comparisons difficult. For the "shuttle test", photocells were placed at the start and end of a 5 m distance. As fast as possible, the fencer moved with correct fencing steps forward and back between them covering a total distance of 30 m.

In a similar study, Tsolakis *et al.,* (2010) correlated anthropometric and physiological traits with performance specific patterns in fencing. The results (as reported above) were used to estimate which variables best predicted performance, as measured by time of lunge and shuttle test described above. Their results revealed that the squat jump, countermovement jump and reactive strength index were all significantly correlated to lunge time (r = -0.46, -0.42 and -0.41 respectively) and shuttle test scores (r = -0.70, -0.63 and -0.44 respectively). As can also be noted here, concentric explosive strength and SSC mechanics are important qualities to fencing performance. In particular, the best single predictor for the time of lunge and shuttle test was squat jump, although all lower-body power tests showed significant relationships. This finding is in line with the suggestions made previously regarding important characteristics of the lunge, in particular, the significance of maximum strength.

The results above reveal some key anthropometric data (including strength and power characteristics). Arguably, these could have been correlated to more direct measures of lunge ability and more specific measures of fencing agility. For example, measuring a full lunge rather than one that is determined by leg length dimensions, would also account for flexibility and arm span, which have also been identified as important factors. Furthermore, the time taken for the chest to break through the beam may not represent the time taken for the sword to make contact with the target; it also neglects the significance of arm velocity, which is considered fundamental. That said, its ability to differentiate between level is indicative of its merits, especially as its measuring equipment is relatively more common place in training

facilities. Finally, while the shuttle test described above can distinguish between levels, it arguably measures change of direction speed over a greater distance and time than a fencer may be expected to perform in any single point; also, changes in direction are likely to be over varying distances. Perhaps a shorter agility test is warranted, from which predictor variables can be calculated. It would be useful to have TMA data that identifies average distances covered and changes in direction per point, noting that each sword may demonstrate a different profile.

2.9 CONCLUSION

Fencing is an explosive sport requiring energy production predominately from anaerobic sources. Lunging and change of direction speed appear vital to performance and strength and power qualities underpin this. In the elimination rounds, fencers are likely to accumulate high levels of blood lactate, so high intensity interval training is recommended to reduce the intolerance to and accumulation of, hydrogen ions. Injury data reports the hamstrings as a muscle group that should be strengthened, as well as addressing imbalances caused by continuous fencing in an asymmetrical stance. Compared to other sports however, injury rate is low.

Further research, to support the work of the sport science team, should centre on defining the physical characteristics that underpin CODS, lunging, and the ability of fencers to maximally execute these throughout a competition. Competition demands must also be detailed so that training programmes optimally prepare fencers for the metabolic demands of each bout; such information provides a measure for which the validity of exercises and programme structure can be appraised.

2.10 PART TWO. DEVELOPING REPEAT SPRINT ABILITY

Repeat sprint ability (RSA) describes the capacity of an athlete to recover and maintain maximal effort during subsequent sprints; an attribute considered important to team sports. RSA should also be seen as synonymous with the frequent bouts of high intensity activities that many combat athletes engage in, such as that which defines the sport of boxing, taekwondo and fencing for example. As such, sprints in the context of this chapter can be inferred to relate to all high intensity actions. RSA is normally trained and measured via high-intensity sprints, interspersed with brief recovery bouts (≤ 30 s); this type of training often defines high intensity interval training. Most strength and conditioning coaches agree that for validity and dynamic correspondence, the RSA training session or testing protocol should resemble the work/rest ratio (W/R) and movement mechanics of the sport in question. What is less clear, are the physiological variables most responsible for improving RSA. This coupled with how to report results will be the topic of this chapter. For the purposes of this review, the term sprint refers to efforts of ≤ 6 s, whereby peak power or velocity could be maintained throughout the repetition. This sprint duration is considered valid as a review of RSA by Spencer *et al.,* (2005) found that field-based team sports are quite consistent in mean sprint time and distance, 2-3 s and 10-20 m respectively. To appreciate RSA, we must first examine how energy is derived and the biochemical production of power.

2.11 ENERGY SUBSTRATES

All energy originates from the sun (i.e., light energy) before being converted to and stored as chemical energy in plants (via photosynthesis); humans obtain this energy by eating the plants or the animals that feed on them. This yields three basic fuels, carbohydrates (CHO), fats and proteins, and each cell houses chemical pathways capable of converting these in to

usable energy – this defines bioenergetics and their associated chemical reactions define metabolism.

Ultimately the energy from these nutrients is released when their bonds – typically consisting of carbon, hydrogen, and oxygen and in the case of protein, nitrogen – are broken. Given the relative weakness of these bonds, little energy is released, thus food is used to synthesise adenosine triphosphate (ATP; considered the "energy currency" of life) and in turn, the hydrolysis of ATP produces muscular contraction. While more energy (expressed in kilocalories; kcal) is released through the breakdown of fat than CHO (9 *vs.* 4 kcal/g respectively; with ATP hydrolysis yielding 10 kcal per mole of ATP), energy release is to slow from fat owing to the extensive bioenergetics involved, and protein (although also slow) is preferably spared for enzymatic functions and structural building. For purposes of RSA therefore, CHO (coupled with phosphocreatine, described below) becomes the preferred substrate. CHO is stored as glycogen in the cytoplasm of the muscle cell and in the liver (where it is converted back to glucose and transported by blood when needed), and its relatively simpler bioenergetics provides a quicker source of energy. Stores of CHO however, are less plentiful than fats (~ 2,500 *vs.* > 70,000 kcal respectively) and as such; appropriate nutrition will also help maintain RSA over prolonged periods. Finally, and while beyond the scope of this chapter, glucose is the only fuel source that can be utilised by the brain, therefore glycogen depletion may affect cognition and thus decision making skills which are also integral to RSA (Meeusen, Exercise, Nutrition and the Brain, 2014).

2.12 THE BIOCHEMISTRY OF RSA

Running parallel with the ability to sustain repeated sprints (i.e., capacity) is the maximal speed (i.e., power) of each sprint. Power is a reflection of the intensity of muscle contraction and the rate at which ATP is being used; e.g., sprint speed is related to the ability to deplete large amounts of high-energy phosphates at a fast rate (Hirvonen, Rehunen, Rusko, & Härkönen, 1987). The human muscle typically stores 20-25 mmol/kg dry muscle (dm) of ATP. At a peak ATP turnover rate of around 15 mmol/kg dm/sec, that's enough to fuel 1-2s of maximal work (Gaitanos, Williams, Boobis, & Brooks, 1993). Therefore from a metabolic perspective, power is dictated by the amount and rate at which ATP is synthesised and then hydrolysed. ATP is never actually fully depleted (as it is used for basic cellular functioning too), depleting by 45% in a 30 s sprint (Boobis, Williams, & Wooton, 1982) and between 14-32% in a 10 s sprint (Jones, et al., 1985). As ATP stores are broken down, various metabolic pathways (energy systems) collaborate to resynthesise ATP and maintain peak rates of turnover. However, with respect to the energy systems used to then resynthesise ATP, there is a trade-off between power and capacity. The contribution of each energy system is determined by exercise intensity and the duration of the rest period (Glaister, 2005). The energy systems are phosphocreatine (PCr), anaerobic glycolysis and the aerobic/oxidative system; these are briefly discussed in turn.

2.13 PCR

There are around 80 mmol/kg dm of PCr stored in the muscle (Gaitanos, Williams, Boobis, & Brooks, 1993) – around three times the amount of ATP - and with a turnover rate of around 9 mmol ATP/kg dm/sec (Hultman & Sjöholm, 1983), stores are largely depleted within 10s of

sprinting (Glaister, 2005). The PCr system has the fastest ATP turnover rate of all energy systems, as there is only one enzymatic reaction (compared to the nine that occur with glycolysis). As with ATP, and because of the contribution made by the other pathways, PCr is not normally depleted. For example, over 30 s PCr is only depleted by 60-80% (Boobis, Williams, & Wooton, 1982), 10 s 40-70% (Jones, et al., 1985), 6 s 30-55% (Boobis, Williams, & Wooton, 1982) and 2.5 s (of electrical muscle stimulation) 26% (Hultman & Sjöholm, 1983); these results suggest that the ATP for short sprints are also heavily subsidised by anaerobic glycolysis.

PCr is resynthesised by the aerobic system and thus its contribution to subsequent sprints is governed by the length of rest period; it resynthesises at around 1.3 mmol/kg dm/s (Gaitanos, Williams, Boobis, & Brooks, 1993). Approximately 84% of PCr stores are restored in 2 min, 89% in 4 min and 100% in 8 min (Harris, Edward, Hultman, Nordesjo, Nylind, & Sahlin, 1976; Hultman, Bergstrom, & Anderson, 1967). Because the recovery of power output maps the time course of PCr resynthesis (Bogdanis, Nevill, Boobis, Lakomy, & Nevill, 1995; Sahlin & Ren, 1989; Sargeant & Dolan, 1987) and is attenuated by creatine supplementation (Mujika, Padilla, Adilla, Ibanez, Izquierdo, & Gorostiaga, 2000; Yquel, Arsac, Thiaudiere, Canioni, & Manier, 2002), PCr availability is likely to be a major factor governing the rate of fatigue (Glaister, 2005). Of note, a molecule of ATP is used to resynthesize PCr and is a reaction used when energy demand is low, enabling stores of PCr to be replenished.

While adaptations to the PCr system likely include increases in the enzymes creatine kinase and myokinase (catalyses the phosphorylation of two ADP molecules to ATP and AMP), Costill *et al.,* (1979) suggested incidences where these increases were non-significant. These investigators examined the effects of a 6 *vs*. 30 s maximal knee extension programme, the former affecting ATP-PCr system and the latter the glycolytic system. The two interventions showed the same gains in strength of 14% and similar resistance to fatigue. However, the anaerobic enzymes creatine kinase and myokinase only increased in the 30 s training group, leading the researchers to conclude that training of programmes of ≤ 6 s improve strength only, with improvements in performance by virtue of less effort to complete a given task.

2.14 ANAEROBIC GLYCOLYSIS

During brief maximal sprints, the rapid drop in PCr is offset by increased activation of glycolysis. Glycolysis describes the breakdown of glycogen in the muscle or glucose in the blood to resynthesise ATP. The maximal turnover rate of ATP production via glycolysis is around 5-9 mmol/kg dm/sec (Gaitanos, Williams, Boobis, & Brooks, 1993; Hultman & Sjöholm, 1983; Jones, et al., 1985; Parolin, Chesley, Matsos, Spriet, Jones, & Heigenhauser, 1999). This system involves multiple enzymatic reactions, so it is not as fast as the PCr system but the two combine to maintain an ATP turnover rate of 11-14 mmol/kg dm/sec (Boobis, Williams, & Wooton, 1982; Gaitanos, Williams, Boobis, & Brooks, 1993). The rapid onset of anaerobic glycolysis with maximal work can be noted by studies that report high values of lactate (> 4 mmol) within 10s (Boobis, Williams, & Wooton, 1982; Jones, et al., 1985). Surprisingly, values as high as 40 mmol/kg dm (Dawson, et al., 1997) and 4 mmol/kg dm (Hultman & Sjöholm, 1983) have been recorded after just 6s sprint cycling and 1.28s of electrical stimulation respectively.

With intramuscular stores of around 300 mmol/kg dm (Gaitanos, Williams, Boobis, & Brooks, 1993), glycogen availability is not likely to majorly compromise ATP provision during the repeated sprints typically used during investigatory studies (Glaister, Stone, Stewart, Hughes, & Moir, 2005). Instead, it may be the progressive changes in metabolic environment (as noted by the aforementioned high lactate values) that ultimately cause a reduction in ATP provision via this system. For example, Gaitanos *et al.,* (1993) using 10 x 6 s sprints with 30 s rest periods, found that the first sprint produced ATP using 50% PCr and 44% glycolysis, while the tenth used 80% PCr and 16% glycolysis; this was accompanied by a 27% loss in power output, an 11.3 mmol/l increase in lactate and a significant drop in ATP production rate. Of note, in field-based team sports, glycogen-loading strategies are important in minimising performance decrements (Spencer, Bishop, Dawson, & Goodman, 2005). For example, in soccer, players with the lowest glycogen concentration at half time covered less distance in the second half than those with the highest concentrations (Saltin, 1973). However, the significance of such loading may only become apparent as sprint frequency increases and rest periods become long enough to again fully engage anaerobic glycolysis. Adaptations to this system include increases in the enzymes phosphorylase, phosphofructokinase and lactate dehydrogenase. Of course and in general, increasing the amount of a particular enzyme involved at each step of the biochemical pathway or by increasing its activity – through changes in temperature or pH for example – will increase metabolism and the production or hydrolysis of ATP.

2.15 CAUSES OF FATIGUE

The anaerobic conversion of pyruvate yields lactate and H^+. Lactate however, is not the cause of fatigue (Brooks, Fahey, & Baldwin, 2005) and can be used as an energy substrate via gluconeogenesis (formation of glucose from non-carbohydrate sources) where it is transported in the blood to the liver, referred to as the Cori cycle, or converted within the muscle fibre itself. Instead the H^+ accumulation, via the formation of lactic acid, decreases intracellular pH, which in turn inhibits oxidative phosphorylation and glycolytic enzymes (such as PFK) and the binding of calcium to troponin and thus muscle excitation-contraction coupling (Nakamaru & Schwartz, 1972). Therefore the removal of H^+ from skeletal muscle is likely to be of importance for the ability to sustain RSA (Pilegaard, Domino, Noland, & Bangsbo, 1999). For example, while trained and untrained may have similar release rates of lactate and H^+ during intense exercise, the intracellular-to-interstitial gradients of these are lower in the trained population (Sahlin & Henriksson, 1984). Combined, these results suggest a trainable buffer capacity that may be key to sustained RSA performance.

2.16 BUFFER CAPACITY

The transient nature of the physiological pH (i.e., 7.4), which is affected by changes in H^+, is governed by a series of buffering mechanisms. These attenuate the effects of H^+ on metabolism by removing hydrogen ions when the pH declines (creating an acidic environment) and by releasing hydrogen ions when the pH increases. There are both intracellular (i.e., protein and phosphate groups) and extracellular (i.e., proteins, Hb, and the bicarbonate pool) buffers.

As the H^+ diffuses out of the muscle into the blood, they are buffered by bicarbonate (via the bicarbonate buffering system), thus attenuating changes in plasma pH by shifting the chemical equilibrium according to Le Chateliers principle. For example, any excess H^+ will associate with bicarbonate forming carbonic acid, thus resulting in a smaller net increase in acidity. The reaction is illustrated in equation one. This buffering system is further facilitated by an increase in respiration rate to remove excess CO_2 and thus acidity. Interestingly, one of the reasons you vomit during high intensity training is that this provides the quickest means to remove large amounts of acid – the stomach is full of hydrochloric acid. In a similar way to bicarbonate, phosphate ions (see equation two) and carnosine act as intracellular buffers. Carnosine is a dipeptide formed of two amino acids, beta-alanine and histidine, with the former often regarded as an ergogenic aid to RSA type activities (Artioli, Gualano, Smith, Stout, & Lancha, 2010).

Equation one. **Where CO_2 = carbon dioxide, water = H_2O, carbonic acid = H_2CO_2, hydrogen = H^+ and bicarbonate = HCO_3^-.**

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

Equation two. **HPO_4^{2-} = hydrogen phosphate, H^+ = hydrogen and PO_4^{3-} = phosphate**

$$HPO_4^{2-}\ H^+ + PO_4^{3-}$$

2.17 AEROBIC METABOLISM

Unlike the anaerobic production of ATP that occurs in the cytoplasm of the cell, oxidative production occurs in the mitochondria. Here, pyruvate is converted to acetyl coenzyme A (rather than lactic acid), where it then enters the Krebs cycle and then the electron transport chain, before yielding 28 moles of ATP (*vs.* one from PCr and 2 or 3 from glycolysis). This system contributes to ATP provision sooner than commonly believed. For example, during the first 6s of a 30s maximal sprint (Parolin, Chesley, Matsos, Spriet, Jones, & Heigenhauser, 1999), or the first 5s of a 3 min intense bout (> 120% VO_2max) (Bangsbo, Krustrup, González-Alonso, & Saltin, 2001), an ATP turnover rate of 1.3 mmol ATP/kg dm/sec and 0.7 mmol ATP/kg/s respectively was hypothesised, both contributing around 10% of total energy produced. Also, as sprints are repeated, the VO_2 of successive sprints will increase (Gaitanos, Williams, Boobis, & Brooks, 1993; Spencer, Bishop, Dawson, & Goodman, 2005) if recovery periods are not sufficient to resynthesise PCr, oxidise lactate and remove accumulated intracellular P_i (through ADP phosphorylation via myokinase). However, while VO_2 uptake may increase with successive sprints, the supply of ATP made by the aerobic system is significantly less than required for repeated sprints (Gaitanos, Williams, Boobis, & Brooks, 1993) and uses a lower ATP turnover rate. As such, while this could guard against a build-up of fatiguing by-products (and sprint frequency/duration can be increased), it would not be able to sustain power output (i.e., sprint performance).

RSA tested under hyperoxic (hypobaric chamber) (Charles, et al., 1996; Hogan, Kohin, Stary, & Hepple, 1999) conditions or those with enhanced oxygen availability (via erythropoietin injection) (Balsom, Ekblom, & Sjodin, 1994) report superior results; the opposite is true for hypoxic conditions (Balsom, Gaitanos, Ekblom, & Sjodin, 1994). The consensus is that a

greater quantity of PCr at the start of each sprint would reduce the demand on anaerobic glycolysis (and concomitant fatiguing by-products e.g., H^+ and P_i) and enhance ATP turnover (Glaister, Stone, Stewart, Hughes, & Moir, 2005). Glaister (2005) concludes that the key role of the aerobic system during repeated sprints is the return to homeostasis during rest. The natural assumption is that aerobic endurance training, by virtue of increasing $\dot{V}O_2$max, will increase recovery rates and thus improve RSA; this is discussed later. Furthermore, increases in aerobic capacity, which are usually consequential to increases in capillary and mitochondrial density, blood volume (including red blood cells) and the percentage of type I fibres (Kenney, Wilmore, & Costill, 2011), usually also increase an athlete's lactate tolerance (Helgerud, Hoydal, Wang, Karlsen, Berg, & Bjerkaas, 2007). By virtue of this, there is a later onset of lactate accumulation.

2.18 SPRINT DURATION, RECOVERY TIME AND RSA

In summary, maximal effort sprints rely on a fast and constant turnover of ATP, powered by the PCr system and anaerobic glycolysis (Gaitanos, Williams, Boobis, & Brooks, 1993). As such, sprint speed is related to the ability to deplete large amounts of high-energy phosphates at a fast rate. If performance is to be maintained across successive sprints, rest periods must be sufficient enough to allow the aerobic system to resynthesise PCr and buffer H^+. It is clear that sprint duration, recovery time and their interaction affect RSA and energy system contribution. For example, sprints of around 5 s performed every 120 s show no significant decreases in performance after 15 sprints. Only when recovery is reduced to 90 s does fatigue significantly affect sprint time, but this is only after the eleventh sprint (Balsom, Seger, Sjodin, & Ekblom, 1992) Also, Balsom *et al.,* (1994) found that 40 x 15 m sprints (around

2.6 s), with 30 s rest could be completed without any reduction in performance. However, 30 m (4.5 s) and 40 m (6 s) sprint times increased significantly and after only the third 40 m sprint, times were already significantly longer.

2.19 TRAINING RSA

Having discussed the biochemical factors governing RSA, the aim of the following sections is to briefly outline how we can train to improve RSA; whether increasing aerobic power ($\dot{V}O_2$max), anaerobic power (speed/ strength/power), lactate threshold or buffering capacity is beneficial. This will be followed by suggestions for reporting results from RSA testing protocols and the requirements for future research within this area.

2.19.1 $\dot{V}O_2$max

Because rest periods are often too short, the assumption is that a higher aerobic capacity ($\dot{V}O_2$max) will lead to quicker recovery and thus improved RSA. However, there are conflicting findings regarding this relationship, which appear largely attributable to the RSA test used. For example, a moderate correlation (r = -0.35) between $\dot{V}O_2$max and RSA was found when using 8 x 40 m sprints with 30 s of active recovery between sprints (Aziz, Chia, & Teh, 2000) but not 6 x 20 m sprints with 20 s of recovery between sprints (Aziz, Mukherjee, Chia, & Teh, 2007). Bishop *et al.,* (2004) utilised an RSA involving 5 x 6 s cycle sprints, departing every 30 s, and found a relationship between RSA and $\dot{V}O_2$max of r = 0.60. The discrepancy

is likely attributable to the length of the sprints used, as this may alter the contribution of the aerobic system (Balsom, Seger, Sjodin, & Ekblom, 1992). In essence, $\dot{V}O_2$max has not been reported to relate to RSA when sprints of less than 40 m (or 6 s) have been used (Da Silva, Guglielmo, & Bishop, 2010). Also, in protocols using W/R ≥ 1/5, there may be sufficient recovery provided for the aerobic system to resynthesise ATP and PCr despite fitness levels. While the issue of whether RSA is affected by a high $\dot{V}O_2$max seems dependent on the protocol used, one must consider the tests validity to the sport in question (discussed later – see 'ecological validity and future research' section).

2.19.2 Lactate Threshold

Most studies use $\dot{V}O_2$max as the major indicator of aerobic fitness. However, because $\dot{V}O_2$max is largely determined by central factors (Basset & Howley, 2000), RSA may more strongly correlate with peripheral factors (Spencer, Bishop, Dawson, & Goodman, 2005). For example, Da Silva *et al.,* (2010) showed that an RSA test consisting of 7 x 35 m sprints (involving a change of direction) and a between-sprint recovery period of 25 s, produced high values of lactate (15.4 ± 2.2 mmol/L) thus demonstrating the large contribution of anaerobic glycolysis. Logically, Da Silva *et al.,* (2010) found that the velocity at onset of blood lactate accumulation (vOBLA) better correlated with RSA performance (r = -0.49); vOBLA reflects peripheral aerobic training adaptations and is associated with an increased capillary density and capacity to transport lactate and H^+ (Billat, Sirvent, Py, Koralsztein, & Mercier, 2003; Thomas, Sirvent, Perrey, Raynaud, & Mercier, 2004). Therefore to improve RSA, it appears prudent to target the development of vOBLA.

2.19.3 Anaerobic Power

Da Silva *et al.,* (2010) (protocol aforementioned) and Pyne *et al.,* (2008) (using 6 x 30m sprints with 20s rest) found that the strongest predictor of RSA was anaerobic power i.e., the fastest individual sprint time; this explained 78% of the variance and had a relationship (*r*) of 0.66 respectively. Results suggest that in addition to training targeting the improvement of vOBLA, it should also focus on improving sprint speed, strength and power. Also, Type II muscle fibres contain higher amounts of PCr than type I (Sant'Ana Pereira, Sargeant, Rademaker, de Haan, & van Mechelen, 1996), suggesting that individuals with a greater percentage of fast-twitch fibres (either through genetics or high-intensity training) may be able to replenish ATP faster via the PCr system when working anaerobically.

2.19.4 Buffer capacity

Bishop *et al.,* (Bishop, Davis, Edge, & Goodman, 2004) have shown that muscle buffer capacity (calculated identified in equation three) and RSA (5 x 6 s cycle sprints, departing every 30s) are significantly correlated ($r = 0.72$, $n = 23$) and Edge *et al.,* (2006) have shown that increases in buffer capacity significantly improves RSA. Therefore athletes that can buffer the accumulation of intracellular H^+ (and thus aid in the regulation of intracellular pH) can reduce the subsequent decline in sprint performance. This relationship with buffer capacity and RSA was higher than that for $\dot{V}O_2$max and LT ($r = 0.60$ and 0.55 respectively). The intracellular contents of protein, inorganic phosphate and the dipeptide, carnosine, have been identified as important physiochemical buffers and shown to be affected by training status (Edge, Bishop, & Goodman, 2006). Furthermore, supplementation with sodium bicarbonate (Bishop, Davis, Edge, & Goodman, 2004), beta-alanine (Artioli, Gualano, Smith, Stout, & Lancha, 2010) and a combination of both (Tobias, et al., 2013) have further

supported this. Also noted and aiding buffering capacity, are improvements in the sarcolemmal lactate/ H^+ transport capacity as well as an enhanced content of monocarboxylate transport proteins (MCT1 and MCT4) (Pilegaard, Domino, Noland, & Bangsbo, 1999). The in vivo analysis of muscle buffer capacity can be calculated using the ratio of blood lactate to changes in pH, as illustrated in equation 3.

Equation 3. Calculation of Buffer capacity (β), where Δ = change and La^- = lactate (Sahlin & Henriksson, 1984)

$$\beta = \Delta [La^-)]_i / \Delta pH_i$$

2.20 ECOLOGICAL VALIDITY AND FUTURE RESEARCH

While mean values for W/R are available, they do not suggest the typical movement patterns. This is likely to have a significant affect, as changes in direction, especially those involving large eccentric contractions and the need to stop, will affect energy expenditure. Also, most studies investigating RSA use passive rest during recovery periods (Spencer, Bishop, Dawson, & Goodman, 2005) despite active recovery showing more promise in reducing the drop in performance. For example, an active recovery (*vs.* passive) consisting of cycling at sub-maximal intensities significantly increased peak power using 8 x 6 s cycle sprints with 30 s rest (Signorile, Tremblay, & Ingalls, 1993). The active recovery may have reduced muscle acidosis by speeding up the removal of lactate from the working muscles; this would also increase its use as a fuel source (Signorile, Tremblay, & Ingalls, 1993). Because the vast majority of field-based team sports involve active recovery, its athletes may indirectly be employing this method (Spencer, Bishop, Dawson, & Goodman, 2005).

Another significant issue with the validity of RSA testing is the fact that the players from most sports are expected to maintain RSA over many more sprints than the number used in many of the current protocols. Also, sprints are not done with a unique and constant W/R. Therefore the significance of a high $\dot{V}O_2$max may be more important only after a certain number of sprints (Thebault, Leger, & Passelergue, 2011). Logically, researchers are skeptical to conclude that $\dot{V}O_2$max is not an important variable to RSA until protocols of match duration are performed (Castagna, Manzi, D'Ottavio, Annino, Padua, & Bishop, 2007).

2.21 REPORTING RESULTS

The method of data analysis for RSA testing is largely a question of two alternatives; reporting total (or mean) sprint time for all sprints or the rate of fatigue (or performance drop-off). The latter can be reported by one of two methods; sprint decrement (S_{dec}) or the fatigue index (FI). The formula for each, according to Spencer *et al.,* (2005) is listed below in equations four and five respectively. Unlike the FI, the S_{dec} takes into account all sprints and is less influenced by a good or bad start or finish (Bishop & Spencer, 2011).

Equation 4. Calculation of sprint decrement (S_{dec})

$$S_{dec}\ (\%) = [(S1 + S2 + S3 + \ldots + S_{final})/S1 \text{ X number of sprints}] -1 \text{ X } 100$$

Equation 5. Calculation of fatigue index (FI)

$$FI\ (\%) = [(S_{slowest} - S_{fastest})/S_{fastest}] \text{ X } 100$$

To improve reliability, Spencer *et al.,* (2005) advise that 5 min prior to testing, athletes complete a single criterion sprint. During the first sprint, athletes must achieve at least 95% of this score. Should they fail, the test is terminated and restarted following another 5 min break. While total (or mean) sprint time demonstrates good reliability (CV < 3%), indices of fatigue are much less reliable (CVs 11-50%) therefore the former should be used (Oliver, 2009; Spencer, Fitzsimons, & Dawson, 2006).

2.22 CONCLUSION

Sprint speed is related to the ability to deplete large amounts of high-energy phosphates at a fast rate. This is fuelled by the phosphocreatine (PCr) system and anaerobic glycolysis. Significant involvement (> 10%) from the aerobic system would reduce ATP production rate and thus sprint speed. However, the ability to sprint repeatedly in quick succession is determined by the aerobic system's ability to resynthesise PCr, remove accumulated intracellular inorganic phosphate (P_i) and oxidise lactate during rest periods. Whether this ability can be appreciably improved via a high $\dot{V}O_2$max still remains controversial. It is likely that sports that require repeated high intensity efforts over a prolonged period of time, in which athletes are required to cover > 40 m per interval and regularly produce efforts in excess of 6 s, would indeed benefit from training targeting its development. Based on the above, RSA (as tested by the studies herein) can be improved via anaerobic qualities such as strength, power and speed, along with the athlete's vOBLA and buffering capacity; this is regardless of the between-sport variability in RSA demands. When reporting RSA test results, total or mean time should be used.

2.23 PART THREE. MONITORING TRAINING LOAD, FATIGUE AND RECOVERY

Athletic training is designed to improve sports performance. In strength and conditioning (S&C), this is sought through physical adaptations such as increasing speed, strength and agility. These physical characteristics are targeted through various exercise and volume-load prescriptions, all integrated into a well-designed training programme. Perhaps given less consideration, are the recovery periods, i.e., the phases of the programme where the relentless accumulation of fatigue (defined as the inability to maintain force or power output at the required level) is dissipated. After all, the adaptations we have sought to induce actually occur while the athlete is resting (Bompa & Haff, 2009; Plisk & Stone, 2003); hence the definition of periodization not only focuses on programme design and the phasic integration of biomotors, but also on variability and the management of fatigue (Bompa & Haff, 2009; Plisk & Stone, 2003). Fatigue is also associated with increased risk of injury (Gabbett, 2004), illness (Neville, Gleeson, & Folland, 2008) and reductions in both competition and training performance (Elloumi, Makni,, Moalla, Bouaziz, Tabka, & Chamari, 2012). Of note, ~ 70% of high-level athletes have or will have, experienced overtraining (OT) (Morgan, Brown, Raglin, O'Connor, & Ellickson, 1987), described as a plateau or decrease in performance consequent to training too often, too long or too hard, and not resting enough between training bouts (Eichner, 1995). This is suggestive of the importance of monitoring fatigue and recovery and that possibly neither are undertaken regularly and/or well understood.

Arguably, the ever increasing pressures faced by athletes, including competing for places on a team that are highly prestigious and ultimately financially lucrative, will only see the gamble of increased training at the expense of recovery (and concomitant increased fatigue)

being taken more. As such, S&C coaches should be able to recognize and test for the manifestations of fatigue and establish preventative measures. Given that the training programme is often the leading cause of OT (Meeusen, Gleeson, Rietjens, & Steinacker, 2006), central to this goal is also the calculation of training load. Outlining appropriate monitoring tools to enable these processes is the aim of this section. This chapter will review a variety of protocols from costless questionnaires to the more expensive and time-consuming analyses made at the elite end of sport.

2.24 TRAINING IMPULSE (TRIMP) AND SESSION RATING OF PERCEIVED EXERTION (SRPE)

The first step in monitoring athlete fatigue and preventing OT is quantifying the actual stress of each training session. This is affected by volume and intensity, so both must be measured. Bannister (1991) suggests assessing physical effort through ‘‘training impulse’’ or TRIMP, which involves monitoring average heart rate (HR) during a session and multiplying this by the duration of the session. While this method is appropriate for steady state, aerobic endurance type training (Padilla, Mujika, Orbananos, Santisteban, Angulo, & Goiriena, 2001; Padilla, Mujika, Orbananos, & Angulo, 2000), it fails to reflect the physiological demands of intermittent sport due to the averaging of HR. To overcome this, modified TRIMP methods have been developed using HR zones and total time spent in each zone multiplied by a relevant weighting (Foster, et al., 2001); this also includes a weighting scale to reflect a typical blood lactate response curve to increasing exercise intensity (Stagno, Thatcher, & Van Someren, 2007). For example, The HR-based method proposed by Edwards (1993) uses five intensity phases (HR zones), with scores for each training bout calculated by multiplying the accumulated duration in each HR zone by a multiplier specific to that zone (50–60% of

HR_{max} =1, 60–70% of HR_{max} = 2, 70–80% of HR_{max} = 3, 80–90% of HR_{max} = 4, and 90–100% of HR_{max} = 5) and then summing the scores. The lactate threshold (LT) zone method of Impellizzeri *et al.,* (2004) involves multiplying the time spent in three HR zones (zone 1 below LT; zone 2 between LT and the anaerobic threshold [AT] and zone 3 above AT) by a coefficient (k) relative to each intensity zone (k = 1 for zone 1, k = 2 for zone 2, and k = 3 for zone 3) and then summating the results. Finally, the TRIMP method of Banister (1991), which preceded these, uses the formula: $TD \cdot HR_R \cdot 0.64e^{b.HR_R}$ in which TD is the effective training session duration in minutes, HR_R is defined as $[(HR_{TS} - HR_B)/(HR_{max} - HR_B)]$, where HR_{TS} is the average training-session HR, and HR_B is the heart rate measured at rest. Finally, $Y = 0.64e^{b.HR_R}$, where is a natural logarithm which is equal to 2.712 and b = 1.67 for females and 1.92 for males. See Table 2.11 for example workings out of the above formulas.

Table 2.1. Training Impulse Calculations

TRIMP (Bannister, 1991)
$TRIMP = TD \cdot HR_R \cdot Y$
Where: TD = effective training session duration; HR_R = heart rate ratio; $HR_R = [(HR_{TS} - HR_B)/(HR_{max} - HR_B)]$; HR_{TS} = average training session HR; HR_B = HR measured at rest; HR_{max} = maximally measured HR; $Y = 0.64e^{b.HR_R}$; e = 2.712, b = 1.67 for females and 1.92 for males.
Example: First calculate the heart rate ratio (HR_R), using the session's average (HR_{TS}), resting (HR_B) and maximal (HR_{max}) heart rate and multiple this by training duration (TD) and the weighting factor (Y). Assuming HR_B = 70bpm, HR_{max} = 200bpm and HR_{TS} = 160bpm and TD = 30min then:
• $HR_R = (160 - 70)/(200 - 70) = 90/130 = 0.69$
• Then multiple HR_R by 30 = 20.7
• We can calculate Y separately and assuming the athlete is male, b in the equation = 1.92
• Y = 0.64 x 2.712 ^ (1.92 x 0.69), where ^ = to the power of
• Y = 2.34
• Therefore TRIMP = 20.7 x 2.34 = 48.44 Arbitrary units (AU)

Modified TRIMP (Edwards, 1993)

Multiple the time (min) spent in each of the HR zones by its weighting factor.

Zone 1 = 50–60% of HR_{max} = weighting factor 1

Zone 2 = 60–70% of HR_{max} = weighting factor 2

Zone 3 = 70–80% of HR_{max} = weighting factor 3

Zone 4 = 80–90% of HR_{max} = weighting factor 4

Zone 5 = 90–100% of HR_{max} = weighting factor 5

For example, across a 30 minute session, this may look as follows:

(3*1) + (6*2) + (7*3) + (10*4) + (4*5) = 93AU

LT Zone Method (Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004)

Multiplying the time spent in three HR zones identified below by a coefficient (k) relative to each intensity zone. The sum the results

Zone 1 = below the lactate threshold (LT), k = 1

Zone 2 = between LT and the anerobic threshold (AT), k = 2

Zone 3 = above AT, k = 3

For example, across a 30 minute session, this may look as follows:

(5*1) + (17*2) + (8*3) = 63AU

Even with such adjustments these methods may not be suitable for resistance and plyometric training (discussed further below). Additionally, collecting HR data can be both time consuming and costly. Fortunately, a simpler method of assessing physical effort can instead be obtained by multiplying total exercise duration (in minutes) by each day's exercise rating of perceived exertion (using an adapted Borg Category Ratio; CR-10). This is referred to as session rating of perceived exertion (sRPE) and was devised by Foster (1996; 1998). Like the CR-10, the sRPE translates the athlete's perception of effort into a numerical score between 0 and 10 (Table 2.2), enabling "training load" (TL) to also be calculated for anaerobic training including plyometrics and resistance training (Coutts, Reaburn, Murphy, Pine, & Impellizzeri, 2003; Day, McGuigan, Brice, & Foster, 2004; Foster, Helmann, Esten, Brice, & Porcari, 2001). With respect to the latter, the session's TL is often defined as the number of repetitions performed (rather than duration of the session) multiplied by the sRPE. Scores are generally obtained 30 minutes after the completion of exercise following the question "*How was your workout?"* This time frame ensures that the score is reflective of the entire session rather than just the final part. More recently however, it was found that measurements could be determined as early as 10 minutes after exercise and be just as accurate (Uchida, et al., 2014); anecdotally, doing it at the end of the cool-down provides a good time point. The score provided should represent a global measure of the entire training bout, with Day *et al.,* (2004) concluding that athletes are able to accurately use RPE scales in this context.

Table 2.2 The Borg category ration scale (Borg, 1982) and session RPE scale (Foster, Daines, Hector, Snyder, & Welsh, 1996)

	Category Ratio Scale	Session RPE
0	Nothing at all	Rest
1	Very weak	Really easy
2	Weak	Easy
3	Moderate	Moderate
4	Somewhat strong	Sort of hard
5	Strong	Hard
6		
7	Very strong	Really hard
8		
9		Really, really hard
10	Very, very strong	Just like my hardest race

Despite the cruder method of the sRPE, it has been shown to be valid and reliable for aerobic exercise when compared to TRIMP (Foster, Helmann, Esten, Brice, & Porcari, 2001) and to the percentage of a training session during which the HR is in blood lactate HR training zones (Foster, Hector, Welsh, Schrager, Green, & Snyder, 1995). For example, Wallace *et al.,* (2009) found significant individual correlations in swimming (during interval-based training) between sRPE and commonly used HR-based methods (e.g., TRIMP [r = 0.55–0.92], Edwards [r = 0.57– 0.91], and LT zone method [r = 0.59–0.94]). Also, when measured during rugby league practices (Gabbett, 2004), the correlation between training HR and training sRPE, and training blood lactate concentration and training sRPE, was 0.89 and 0.86 respectively. The correlation between match HR and match sRPE, and match blood lactate concentration and match sRPE, was 0.85 and 0.86 respectively. In addition, two identical off-

season training sessions, performed one week apart, revealed intraclass correlation coefficient for test–retest reliability and coefficient of variation for the sRPE scale were 0.99 and 4.0% respectively (Gabbett, 2004).

In general, stronger correlations are reported in endurance-based athletes (r = 0.75–0.90) (Foster, et al., 2001) and aerobic based sports and training drills (Haddad, Chaouachi, Castagna, Wong, Behm, & Chamari, 2011). As the measured activity becomes more anaerobic, the association between sRPE and HR is reduced and eventually, when highly anaerobic, non-convergent (Haddad, Chaouachi, Castagna, Wong, Behm, & Chamari, 2011; Coutts, Rampinini, Marcora, Castagna, & Impellizzeri, 2009). The requirement for anaerobic metabolism may lead to increased internal TL via increased RPE, without increases in HR, suggesting that HR may not be an appropriate global measure of high-intensity exercise (Haddad, Chaouachi, Castagna, Wong, Behm, & Chamari, 2011). In agreement, Drust *et al.,* (2000) reported increased RPE scores during an intermittent protocol when compared to a steady-state exercise session matched for total work and despite no differences in mean $\dot{V}O_2$ and HR between the two exercise protocols. Also, Coutts *et al.,* (2009) has shown that measures of both HR and blood lactate must be used to more accurately predict RPE. As such, the sRPE, as well as being the most practical means for quantifying internal TL during high-intensity exercise (Haddad, Chaouachi, Castagna, Wong, Behm, & Chamari, 2011; Coutts, Rampinini, Marcora, Castagna, & Impellizzeri, 2009; Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004), may be the best. It represents the combination of many factors affecting internal load of exercise, such as an athlete's psychological state, training status and external training load (Robertson & Noble, 1997). Given the aforementioned data, it may be unsurprising to read that the sRPE has been successfully used in various team

sports (Alexiou & Coutts, 2008; Coutts, Reaburn, Murphy, Pine, & Impellizzeri, 2003; Gabbett, 2004; Manzi, D'Ottavio, Impellizzeri, Chaouachi, Chamari, & Castagna, 2010), taekwondo (Haddad, Chaouachi, Castagna, Wong, Behm, & Chamari, 2011), swimming (Wallace, Slattery, & Coutts, 2009), boxing (Uchida, et al., 2014) and sprint kayak (Borges, Bullock, Duff, & Coutts, 2014). As a final note, when sRPE was used to measure the physical effort of resistance training, it was found that scores were influenced more by load than volume, suggesting athletes find lifting heavier weights harder than performing multiple reps with lighter loads (McGuigan, Egan, & Foster, 2004; Day, McGuigan, Brice, & Foster, 2004; Sweet, Foster, McGuigan, & Brice, 2004). Sweet *et al.,* (2004) and McGuigan *et al.,* (2004) showed that despite the same percentage of 1-RM, sRPE significantly varied depending on involved muscle mass (and hence metabolic demand), range of motion and the number of joints involved. They further suggested that the order of exercise, the athlete's resistance training age as well as the time at which scores are taken would also affect sRPE (Sweet, Foster, McGuigan, & Brice, 2004).

In addition to TL, a score for training monotony (TM) and training strain (TS) can also be calculated (Foster, Hector, Welsh, Schrager, Green, & Snyder, 1995). TM is indicative of a lack of variability in training load. For example, alternating "hard" and "easy" training days would have high variability, however, if the same total training load was instead equally divided into several consecutive "medium" training days, the score for monotony would be high and the athletes would be put at risk of illness, OT and naturally, under-performance (Bruin, Kuipers, Keizer, & Vander Vusse, 1994; Foster, 1998). For example, Bruin *et al.,* (1994) observed symptoms associated with OT in racehorses where the intensity of ''easy'' days was increased in a programme constructed on a ''hard'' day, ''easy'' day basis (training 7 days a week). Such a finding is consistent with the differences in training programme design by coaches versus execution by athletes (Foster, Daines, Hector, Snyder, & Welsh,

1996). It is therefore important that the athlete rates the session, not just because each athlete will perceive it differently, but because coaches tend to rate session intensity lower than athletes, a mismatch that could lead to OT (Foster, Helmann, Esten, Brice, & Porcari, 2001; Wallace, Slattery, & Coutts, 2009).

Because high TL and TM are both factors related to negative adaptations to training, Foster *et al.,* (1995) have suggested that the product of these, TS, may also relate to negative adaptations to training. TM is calculated from the average daily TL divided by the standard deviation of the daily training load calculated over a week. The weekly TS is then calculated as the product of weekly training load and monotony (i.e., TS = TL x TM). Table 2.3 examples a training log whereby TL, TM and TS have been calculated. Of note, on non-training days a score of zero must be entered and included in calculations of weekly training loads, monotony, and strain. If these zero values were not included, then training monotony and strain will appear artificially high. In addition, consistency with respect to the portion of the session analysed must be upheld, e.g., do you collect scores for warm-ups and cool-downs (Comyns & Flanagan, 2013). Finally, caution should be exerted when comparing player scores for TL as some athletes may simply be "high raters" and will consistently rate sessions of the same work output on a higher level to their teammates (Comyns & Flanagan, 2013). Table 2.3 examples the calculation of load, monotony and strain in athletes.

Table 2.3 Schematic evaluation of the load, monotony, and strain associated with a training programme in Olympic fencers.

Day	Session	Duration	sRPE	Session TL	Daily TL
Monday	Gym	50	6	300	940
	Technical	90	6	540	
	Conditioning	10	10	100	
Tuesday	Gym + plyo	60	6	360	690
	Footwork	30	3	90	
	Sparring (6 x 5 hits)	30	8	240	
Wednesday	footwork	15	3	45	945
	Tactical	30	6	180	
	Sparring (5 x 5 hits)	30	8	240	
	Sparring (4 x 15 hits)	60	8	480	
Thursday	Gym + plyo	60	6	360	930
	Footwork	30	3	90	
	Sparring (3 x 15 hits)	60	8	480	
Friday	Gym	50	6	300	935
	Footwork	15	3	45	
	Technical	90	6	540	
	Conditioning	10	5	50	
Saturday	Rest	0	0	0	0
Sunday	Rest	0	0	0	0
Total TL					**4440**
Average daily TL					**634**
SD daily TL					**443**
TM					**1.43**
TS					**6362**

Finally, using TL, Gabbett (2004) also found a significant relationship between the incidence of training injuries and the intensity (r = 0.83), duration (r = 0.79) and load (r = 0.86) of training sessions. In addition, the incidence of match-play injuries was highly correlated with the intensity (r = 0.74), duration (r = 0.86) and load (r = 0.86) of matches. Their findings were also able to deduce that the 38.5% increase in TL over the 12-week period, corresponded with a 95.4% increase in the incidence of injuries sustained during training. This may suggest that the prescribed increase in TL was greater than was tolerable for the musculoskeletal system. Both Foster (1998) and Brink *et al.,* (2010) have also used TL (Foster also used training monotony and strain as aforementioned) to predict the occurance of injury and illness. These may occur when an athlete's individual threshold for training tolerance has been breached (see Figure 2.3).

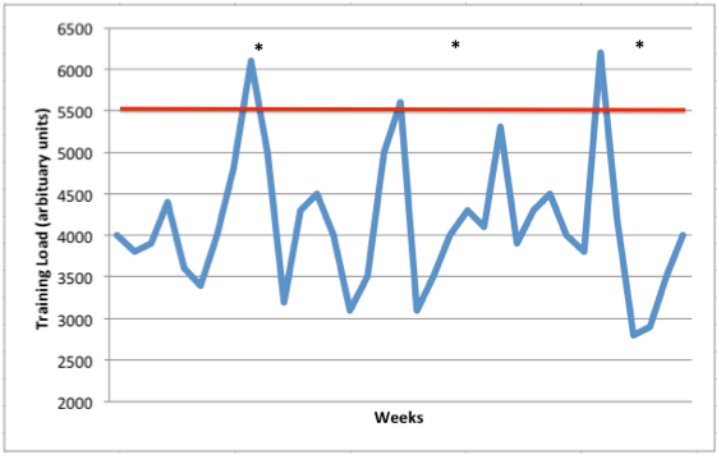

Figure 2.3 Hypothetical schematic graph of weekly training load for an individual athlete. Also plotted is the threshold for training for this athlete (identified as 5500 arbitrary units), above which, appears correlated to injury or illness (as represented by '*').

Having addressed the collection of TL, the next sections will review the methods by which its associated fatigued can be monitored, to ensure training is always optimised, training adaptations are not compromised and overtraining syndrome is not risked.

2.25 QUESTIONNAIRES

Analysis of fatigue and general wellbeing by virtue of questionnaires is a popular method given its non-invasive nature, accessibility including being (often) freely available, and of course, the relationship several of them show to performance measures (discussed below). Given their use to predict fatigue, they are now regularly completed by athletes, thus allowing results to have an immediate effect on the weeks TL. As such, questionnaires must be short, unambiguous and scores easy to compute. From the sections below, this trend can be noted as well-established, validated questionnaires are gradually made specific to sport, shortened and eventually, seem to be devised by the sport science team, consisting of only a few (≤10) key questions, limited (≤7) answers to choose from and daily completion to thus affect daily TL. Several questionnaires are discussed below

2.25.1 Profile of mood states (POMS)

The Profile of Mood States (POMS) questionnaire measures the psychology of mood state, mood changes and emotion (McNair, Lorr, & Droppleman, 1971). It was initially designed for patients undergoing counselling or therapy, but has evolved to be used in sport. Well rested athletes tested prior to training report high scores for vigour and low scroes for tension, depression, anger, fatigue and confusion to reveal the “iceberg profile”. Monitoring POMS has helped predict success and prevent OT in speed skaters (Gutmann, Pollock, Foster, & Schmidt, 1984), rowers (Raglin, Morgan, & Luchsinger, 1990), canoeists (Berglund &

Safstrom, 1994) and track and field athletes (Raglin & Morgan, 1994). Changes in mood disturbance are calculated by summing the five negative scores, adding 100, and subtracting the one positive mood score (vigour). There are 65 items in all, with the respondent answering according to a scale (0 = not at all, 1 = a little, 2 = moderately, 3 = quite a bit, 4 = extremely). Regular completion of the POMS would allow a baseline score to be established; deviations from this could provoke discussions with the sport science team. A shortened POMS questionnaire is also available (Grove & Prappavessis, 1992) but its increased practicality may have diminished its sensitivity to changes in training load (Rietjens, Kuipers, Adam, Saris, Van Breda, & Van Hamont, 2005).

Using the POMS, Filaire *et al.,* (2001) found that soccer player's moods improved with an increase in winning performances despite an increase in the intensity of training. They also found an increase in depression and tension during a period of poor performance, despite levels of fatigue, relationships between players and coach and financial and family problems appearing unchanged. They therefore suggested that the changes in POMS during this period might have been affected by factors other than those relating exclusively to training or external personal influences. Collectively however, studies have shown that scores on the POMS are: a) predictive of performance (Beedie, Terry, & Lane, 2000), b) useful indicators of over-training (Berger, Motl, Butki, Martin, Wilkinson, & Owen, 1999), and c) related to changes in environmental factors such as altitude, heat and cold (Lane, Terry, Stevens, Barney, & Dinsdale, 2004). Others advise that the POMS test can be informative, providing other information about the athlete is collected simultaneously (Lambert & Borresen, 2006). However, the fact it was not designed specifically for sport and can be quite time consuming has hampered its wide spread use to monitor the recovery processes of athletes. Equally, anecdotal evidence has revealed that athletes have concerns over the sharing of such

information amongst sport science and coaching staff, when results are thought to affect their place on a team. As such, shorter, less intrusive tests have been developed, whereby general wellbeing is holistically assessed.

2.25.2 Brunel Mood Scale (BRUMS)

A few issues have been raised regarding the use of the POMS, such as its use with adolescents (Terry, Lane, Lane, & Keohane, 1999). For example, The POMS and its associated tables of normative data were derived from adults and psychiatric outpatients; the test manual also recommends its use with those aged 18 and older (McNair, Lorr, & Droppleman, 1971). Furthermore, the 65-item POMS has been criticized for taking too long to complete (Shacham, 1983; Grove & Prappavessis, 1992; Curren, Andrykowski, & Studts, 1995), which can effect its use before competitions, at the start of a lesson, or general day to day use (Terry, Dinsdale, Karageorghis, & Lane, 2006). Also, for adolescents in particular, the comprehensibility of the questionnaire must be considered. Consequent to these concerns, Terry et al. (1999) developed the POMS-Adolescents (POMS-A). This was a shorter questionnaire (now only 24 items), with more age appropriate language (as determined by a panel of school teachers and children). The POMS-A was then changed to the Brunel Mood Scale (BRUMS) as it was later validated for use with adult athletes (Terry, Lane, & Fogarty, 2003). The BRUMS has since been validated for specific-sports (Fazackerley, Lane, & Mahoney, 2003) and has been cross-validated for use with Hungarian, Italian (Lane, Soos, Leibinger, Karsai, & Hamar, 2007) and Malaysian athletes (Hashim, Zulkifli, & Ahmad, 2010). There is now also normative data for use with UK athletes (Terry & Lane, 2010) and yet more with Malaysian athletes (Lan, Lane, Roy, & Hanin, 2012), both of which can help practitioners interpret raw scores. The simplicity of the POMS-A (BRUMS) is advantageous and can assess mood shortly before/after competition without disturbing to a great extent

athletes' normal routines. Arguably however, 24 questions may still prove too long for daily use and thus better on a once weekly basis. Also, like the POMS this questionnaire must be purchased.

2.25.3 Daily Analyses of Life Demands for Athletes (DALDA)

The Daily Analysis of Life Demands for Athletes (DALDA) is a sport specific test to monitor an athlete's stress of training (Rushall, 1990). This test aims to identify both the cause (Part A) and symptoms (Part B) of stress (Figure 2.4). The *DALDA* can be used every day, periodically (once every two or three days) or if need be, weekly (Robson-Ansley, Blannin, & Gleeson, 2007) throughout a period of training. It is important to establish the training response "window", described as the baseline set of responses against which training assessments are compared (Figure 2.5). This requires the consistent self-assessments of training-stress symptoms over a period of at least two weeks to determine minimum and maximum values for each athlete; this should therefore be done during a fairly constant phase of training. Establishing these windows enables coaches to identify periods of excessive fatigue whereby training load should be reduced, as well as peaking phases through which fatigue has been diminished and performance is likely to be heightened (see Figure 2.5). Several studies report its sensitivity to TL (Halson, Bridge, Meeusen, Busschaert, Gleeson, & Jones, 2002; Robson-Ansley, Blannin, & Gleeson, 2007; Achten, Halson, Moseley, Rayson, Casey, & Jeukendrup, 2004) with significant increases in the symptoms of stress also being indicative of an impending reduction in immune system functioning (Robson-Ansley, Blannin, & Gleeson, 2007). As well as providing valuable information to the coach, it may also be a useful daily tool for developing an athlete's self-awareness of sources and symptoms of physical and psychological stressors from both the sporting and non-sporting environment. Also, while it has 34 questions, answers are only "yes" or "no" (for Part B) or

"worse than normal", "normal", or "better than normal" (for Part A), thus expediting its completion.

DALDA Stress Sources (Part A)				DALDA Stress Symptoms (Part B)			
Source	Worse than normal	Normal	Better than Normal	Symptom	Worse than normal	Normal	Better than Normal
Diet				Muscle pains			
Home-life				Techniques			
School/college/work				Tiredness			
Friends				Need for rest			
Training and exercise				Supplementary work			
Climate				Boredom			
Sleep				Recovery time			
Recreation				Irritability			
Health				Weight			
				Throat			
				Internal			
				Unexplained aches			
				Technique power			
				Enough sleep			
				Between session recovery			
				General weakness			
				Interest			
				Arguments			
				Skin Rashes			
				Congestion			
				Training effort			
				Temper			
				Swellings			
				Likability			
				Running nose			

Figure 2.4 The Daily Analysis of Life Demands for Athletes (DALDA) questionnaire which aims to identify both the cause (Part A) and symptoms (Part B) of stress (Rushall, 1990).

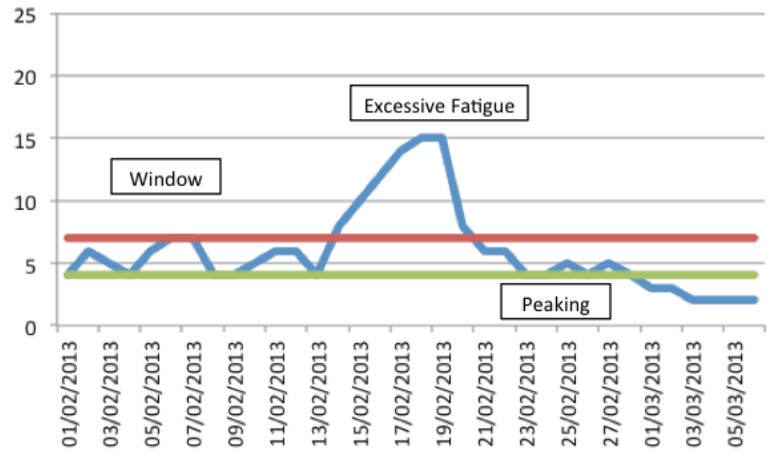

Figure 2.5. Graphed scores of daily DALDA (Part B). The first 10 days were used to define the training response window; the red line represents the upper boundary while the green line represents the lower boundary. Scores that go above the upper body indicates excessive fatigue, while score below the lower body suggest the athlete optimally prepared for competition.

2.25.4 The Short Questionnaire of Fatigue (SQF)

Chatard *et al.,* (Chatard, Atlaoui, & Pichot, 2003) have developed a shorter, quicker-to-complete questionnaire, which consists of only eight-items focused on the perception of training, sleep, leg pain, infection, concentration, efficacy, anxiety, irritability, and general stress; it is titled ‘‘the short questionnaire of fatigue’’ (SQF) (Figure 2.6). This questionnaire has been validated as a sensitive tool to the variations of TL and performances in swimmers (Atlaoui, Duclos, & Gouarne, 2004) and rugby sevens players (Elloumi, Makni,, Moalla, Bouaziz, Tabka, & Chamari, 2012). Each question is assessed on a 7-point scale, from not at all (1 point) to very much (7 points), with responses summed to obtain the total score of fatigue (TSF). The lower the score, the better the perception of general wellbeing, the higher the score, the higher the perception of fatigue.

	During the preceding week:	**Not at all**		**Normal**		**Very much**		
1	I found training more difficult than usual	1	2	3	4	5	6	7
2	I slept more	1	2	3	4	5	6	7
3	My legs felt heavy	1	2	3	4	5	6	7
4	I caught cold/infection/flu	1	2	3	4	5	6	7
5	My concentration was poorer than usual	1	2	3	4	5	6	7
6	I worked less efficiency than usual	1	2	3	4	5	6	7
7	I felt more anxious or irritable than usual	1	2	3	4	5	6	7
8	I had more stress at home/school/training/work	1	2	3	4	5	6	7

Figure 2.6 The short questionnaire of fatigue by Chatard et al., (2003)

Across 8-weeks training (6-week intense training and 2-week reduced training) involving 16 elite rugby 7s players, Elloumi *et al.,* (2012) compared the SQF to the sRPE where TL, TM,

and TS was calculated for each athlete as described by Foster *et al.,* (2001). Results were also compared with sport-specific tests such as speed (10, 20, 30-m sprints), agility (Illionois agility run), power (five-jump test) and aerobic endurance (Yo-Yo). Their study showed that TL and TS increased significantly during the intense training period and were associated with an increasing TSF. This also resulted in a decrease of all sport-specific tests. Similarly, as TL and TS decreased during the reduced training period, so too did the TSF, with increases recorded in the physical performance tests. The changes in TL, TS and TSF correlated significantly over the training period (r = 0.63 – 0.83) and changes in TSF were also correlated to agility (Illinois agility run) scores (r ~ 0.6). They concluded by supporting the usefulness of questionnaires in monitoring training load and strain in high-level athletes. In addition, their simplicity and costless mode make them available to all clubs and make regular monitoring feasible.

2.25.5 Total Quality of Recovery Questionaire (TQR)

The Total Quality of Recovery questionaire (TQR) by Kentta and Hassmen (1998) (also see (Kenttä & Hassmén, 2002)) is a well regarded tool for monitoring behaviours that may lead to fatigue and eventually OT. In essence, it addresess the efficacy of recovery interventions aimed at alleviating training stress. Their questionnaire is divided into four sections: (1) nutrion and hydration, (2) sleep and rest, (3) relaxation and emotional support and (4) stretching and active rest (Figure 2.7). The athlete scores points on each section, with the amount available per section dependent on its assumed significance to the recovery process; in total, athletes can score up to 20 points. Athletes fill out the guide before bed each evening with the total revealing whether they are paying adequate attention to their physical and mental recovery needs. Kentta and Hassmen advise that 17-20 daily points is optimal, 15-16 points is good and 12 points or fewer means the athlete needs an individual evaluation of

recovery behaviours. To further make the TQR process user-friendly and relate back to training load and accumulated stress, the scale is mapped to the 20-point RPE scale; the scores for these should match, with the score of the latter based on intensity of training. Like the DALDA, the TQR may also be a useful daily tool for developing an athlete's self-awareness of their recovery process. Anecdotal advice is to adapt the TQR, including the points available and the individual components of each section, based on the demands and realistic expectations of the athletes in questions. This alteration should be done based on the opinions of a multidisciplinary team; the example used within British Fencing has been provided. It may only be necessary to collect TQR data once a month, and emphasis should be placed on its educational value in teaching athletes the important components of recovery.

Recovery Scoring Guide

NATIONAL FENCING ACADEMY

BRITISH FENCING

Athletes should fill out this guide over the course of a week to assess their own recovery behaviors. Once they have scored a full day, the total reveals whether they are paying adequate attention to their physical and mental recovery needs. **17-20** daily points is optimal; **15-16** points is good; **14 or fewer** points means the athlete needs an individual evaluation of recovery behaviors.

Recovery Strategy	Possible Points	Sun	Mon	Tue	Wed	Thu	Fri	Sat	SCORING GUIDE ADJUSTMENTS
Nutrition	**8**								
Breakfast	2								Give one point for a less than full breakfast
Lunch	2								Give one point for a less than full lunch
Dinner	2								Give one point for a less than full dinner
Snacking throughout day	1								
Post-exercise refueling within 30 min	1								
Hydration	**2**								
Pre-exercise urine: clear or light color	1								
Post-exercise urine: clear or light color	1								
Stretching/Cool-down	**4**								
Adequate cool-down after exercise	1								
Stretching for at least 5 minutes	1								
Massage/foam roll/ice bath etc.	1								
Change into dry clothing immediately post exercise	1								
Sleep, Stress and Rest	**6**								
Able to relax post-workout	1								
No daily psycho-social stress	2								Give one point for mild stress
8 hours of restful sleep (in total)	3								Give two points for 7 to <8 hours Give one point for 6-7 hours
TOTALS	**20**								

Figure 2.7 Total Quality of Recovery questionnaire (TQR) by Kentta and Hassmen (1998; 2002) adapted for athletes of the British Fencing National Academy. The sections, components of and scoring allocation can be changed to suit the needs and realistic expectations of different athletes

2.25.6 The Recovery–Stress Questionnaire for Athletes (RESTQ-Sport)

The RESTQ-Sport (Kellmann & Kallus, 2001) assesses the recovery–stress state of an athlete, indicating (1) the extent to which they are physically and/or mentally stressed, and (2) whether or not they are capable of using individual strategies for recovery. The questionnaire uses a Likert-type scale, ranging from 0 (never) to 6 (always), to measure to what extent the athlete took part in different activities within the past 3 days/nights. The RESTQ-Sport consists of seven general stress scales (General Stress, Emotional Stress, Social Stress, Conflicts/Pressure, Fatigue, Lack of Energy, Physical Complaints), five general recovery scales (Success, Social Recovery, Physical Recovery, General Well-being, Sleep Quality), three sport-specific stress scales (Disturbed Breaks, Emotional Exhaustion, Injury), and four sport-specific recovery scales (Being in Shape, Personal Accomplishment, Self-Efficacy, Self-Regulation); in total there are 77 items (19 scales with four items each plus one warm-up item). Question examples include: ‘‘In the past (3) days/nights . . . I felt down’’ (for the scale General Stress), ‘‘In the past (3) days/nights . . . I was overtired’’ (for the scale Fatigue) or ‘‘In the past (3) days/nights . . . I finished important tasks’’ (for the scale Success). The questionnaire is considered to have good internal consistency (Cronbach’s $\alpha = 0.67–0.89$) and the test–retest reliability ($r > 0.79$) of all general scales, allowing athlete to be reliably tracked over time (Kallus, 1995).

The RESTQ-Sport has been used in various sports including rowing (Kellmann & Gunther, 2000; Maestu, Jurimae, Kreegipou, & Jurimae, 2006; Jurimae, Maestu, Purge, & Jurimae, 2004), cycling (Bouget, Rouveix, Michaux, Pequignot, & Filaire, 2006), triathlon (Coutts, Slattery, & Wallace, 2007), swimming (Wallace, Slattery, & Coutts, 2009) and rugby (Elloumi, et al., 2012). In rowing, increases in TL were reflected in elevated stress and reduced recovery scores; the opposite was also true. Furthermore, Steinacker et al. (1999) and

Steinacker et al. (2000) found that scores for “Physical Complaints” during the intensive training phase positively correlated with increased cortisol and creatine kinase; also the peak amount of norepinephrine corresponds to “Fatigue”. Kellman (2010) provides further information on the RESTQ-Sport, including an example individual assessment.

2.25.7 Can you develop your own questionnaire?

More recently, arguably due to the necessity of brevity in applied sports settings (whereby questions must be limited to between 5 and 10) coupled with the requirements for daily assessments, investigators have developed their own psychometric questionnaires (Mclellan & Lovell, 2010; Buchheit & Laursen, 2013), based on previous recommendations (Hooper & Mackinnon, 1995). These act as general indicators of player wellbeing and can be completed each morning enabling the results to effect the days training. The questionnaire of McLean *et al.,* (2010) comprised of 5 questions relating to perceived fatigue, sleep quality, general muscle soreness, stress levels and mood. Each question was scored on a five-point scale (scores of 1–5, with 1 and 5 representing poor and very good wellness ratings respectively and 0.5 point increments) with overall wellbeing then determined by summing the five scores.

Naturally, any questionnaire that has not been validated will be questioned. Validating self-report questionnaires involve the demonstration of its content, factorial, criterion and construct validity, and is usually developed in three stages. This process is exampled through the development of the POMS (see section 2.24.1) as described by Terry *et al.,* (1999). Firstly content (or logical) validly must be established (i.e., the extent to which questions match the subject area they are proposed to assess) whereby a group of experts, representative participants or both are used to select or confirm items that best describe the construct in

question. The POMS was developed using a group of schoolteachers and children, whereby the originally proposed 83 mood descriptors was cut to 42 items, grouped evenly in to six factors. In stage two, confirmatory factor analysis is used to test factorial validity whereby the final model was reduced to a 24 item six factor model. Finally the third stage, to establish criterion validity (i.e., the degree to which scores on a test are related to some recognised standard), tested the extent to which the subscales of the questionnaire correlated with previously validated measures.

In spite of this recognised process, it would appear that at times, applied practitioners develop questionnaires that they have intuitively found affect performance, but ensuring each criterion is supported by research, e.g., muscle soreness (Nguyen, et al., 2009), sleep (Bird, 2013), hydration (Yamamoto, et al., 2008) and nutrition (Robson-Ansley, Gleeson, & Ansley, 2009). Providing scores map back to additional measures of fatigue, rather than relying on the results of the questionnaire only, and they can be completed daily (or at least twice weekly) by athletes without contempt, then such an approach may be justified. It is worth reiterating that questionnaires also act to educate athletes on the important components of recovery, and scores could simply act to start discussions between the sport science team and the athlete, regarding behaviours towards each criterion.

2.26 SPORT-SPECIFIC TESTS

The goal of training athletes is to provide training loads and stress that is effective in improving performance. At some stages of the training process, athletes may accumulate too much fatigue with not enough recovery. Fatigue is an integral part of the training process, without acute fatigue, supercompensation and adaptation would not occur (Zatsiorsky & Kraemer, 2006). During intensified training and general fatigue, strength and power are likely

to remain lower than usual. The fatigue may initially be due to metabolic disturbances, (e.g., metabolite accumulation, depletion of energy substrates and phosphate), hormonal alterations, changes in calcium handling abilities of the sacroplasmic reticulum (Li, Wang, Fraser, Carey, Wrigley, & McKenna, 2002) and neural fatigue (Linnamo, et al., 2000). Subsequent fatigue may then be due to the inflammatory processes associated with muscle damage (Nosake, 2011). Logically then, fatigue can be monitored using isometric strength tests (e.g., mid-thigh isometric pulls) and more commonly, jump tests, especially countermovent jumps (CMJ), Plyometric Push up's (PPu) and measures of leg stiffness or reactive strength index (RSI). While questionnaires may offer the opportunity to obtain internal load, the subjectivity of this process must be considered. Also biochemical measurements (discussed later), although appearing valid and objective, are often very expensive and require a certain degree of expertise in order for results to be obtained. Therefore using a CMJ for example (ideally after establishing a link to biochemical markers) offers a practical application for field based measurements of fatigue.

Jump type monitoring (CMJ, PPu, RSI) is widely incorporated across research and practical field testing due to its high reliability, validity and ease of use (Markovic, Dizadar, Jukic, & Cardinale, 2004; Mooney, Cormack, O'Brien, Morgan, & McGuigan, 2013; Johnston, Gabbett, Jenkins, & Julin, 2014; Johnson, Gibson, Twist, Gabbett, MacNay, & MacFarlane, 2013). Research shows that fatigue accumulation will last from 48-72 hours post exercise/competition through continued deficit in jump performance (Cormack, Newton, & McGuigan, 2008; Mooney, Cormack, O'Brien, Morgan, & McGuigan, 2013; Johnson, Gibson, Twist, Gabbett, MacNay, & MacFarlane, 2013; Coutts & Duffield, 2010). McLellan *et al.,* (2010) found that following a competitive rugby league match, force-time data from a countermovement jump showed that peak rate of force development, peak power and peak

force all dropped immediately after the match and lasted for 48-hrs; this mimicked the bodies stress response as measured by salivary cortisol concentrations (see below). Johnston *et al.,* (2013) reported that the force component was compromised to a lesser extent when compared to peak power (ES = -0.01, trivial; ES = -0.73, moderate) when monitoring rugby league players post competition. This change to the force velocity relationship favours a slower muscle contraction and should be taken into consideration through training.

Other sports specific tests have been used as a monitoring tool. The study of Elloumi *et al.,* (2012) found changes in TSF was correlated to agility (Illinois agility run) scores ($r \sim 0.6$) suggesting that agility could act also as a marker. Kraemer *et al.,* (2004) monitored soccer players and found testosterone and knee flexion strength along with peak isometric torque had significant correlations ($r = 0.55$ and $r = 0.71$), however the equipment used is expensive and not readily avaliable for S&C coaches. Aerobic based tests could also be used, however, this may not be practical as in addition to time constraints, they are likely to further confound the issue of accumulating fatigue.

While performance tests hold promise due to their quick and relatively simple monitoing process, along with directly assessing fatigue specific to sports performance, there is a surprising lack of empirical research into this area. High levels of residual fatigue and markers of muscle damage have the potential to compromise performance through reductions in low and high speed movements. Nevertheless, these tests are considered a convenient and useful indicator of training stress and the S&C coach should consider using them as part of a holistic monitoring process.

2.27 USING SALIVA AS A TOOL TO MONITOR STRESS

The measurement of salivary analytes, e.g., tesestosterone (T), cortisol (C), immunoglobulin A and more recently α -amylase, are becoming more common in professional sport. The concentrations of these biomarkers are regularly used to describe training stress (load) and each athlete's ability to cope with it. Its popularity stems from its non-invasive nature and rapid collection process, including conveinience at competitions and during exercise tests. Also its simplicity means that with only brief training, most researchers and even athletes themselves can collect samples. In the case of T and C, it not only demonstrates a high correlation (r = 0.62-.93) with blood concentrations (see (Papacosta & Nassis, 2011)), but given its nature of entry into saliva, i.e., by passive diffusion through the cell membrane of glands from the surronding cappilaries (Papacosta & Nassis, 2011), the concentrations of these represent only the free, unbound and biologically active steriods (those bound to their binding protein are to big to pass). Given the growing intersest and established use of the aforementioned biomarkers, a discussion of each is warranted.

2.27.1 Testosterone and Cortisol

Testosterone (T) and cortisol (C) are considered valid markers of training load (Cormack, Newton, & McGuigan, 2008; Mclellan & Lovell, 2010); with the former described as the primary anabolic marker for protein signaling and muscle glycogen synthesis, and the latter a stress hormone which mediates catabolic activity, increasing protein degradation and decreasing protein synthesis in muscle cells (see (Turner, Comfort, Moody, & Jeffreys, 2010)). In addition to intensive physical exercise, C is also associated with anxiety, depression and creatine kinase, which is a marker of muscle damage (Kraemer, et al., 1993). The ratio of T and C has been used to define the anabolic:catabolic endocrine profile of

athletes (Cormack, Newton, & McGuigan, 2008); results would be indicative of the stress faced during training and/or competition and their requirements for recovery. McLellan *et al.,* (2010) monitored the T:C response following a rugby league match and reported that the ratio droped the day before the match (likely due to the anticipation and anxiety experienced by the athletes as a precompetitive arousal and coping mechanism used to manage pre-game stress) and did not return to baseline measures until 48-hrs post match. This time point would be indicative of when training could safely resume again without an increased risk of OT, injury or illness. Some studies have shown that high and prolonged elevations of cortisol despite acute recovery may infer OT (Fry, Kraemer, & Ramsey, 1998). Often however, no relationship (including with T:C measures) is found (McGuigan & Cormack, 2011). In summary, if this assessment mode is to be used, weekly collection of C, T and T:C would be required (which is also the case for α -amylase and IgA discussed below) to establish individual baselines for the estimation of optimal *vs.* excessive workloads. Again, due to the complexity of the results, this should be done in conjunction with other measures such as questionnaires and/or performance tests.

2.27.2 α -amylase

The stress response has two principal components. Firstly, the activation of the hypothalamic–pituitary–adrenal (HPA) axis resulting in the secretion of C into circulation. The second (faster acting component) involves activation of the sympathetic branch of the autonomic nervous system (ANS) and the release of catecholamines (Chrousos & Gold, 1992); these are commonly known as the flight or fight response. Understandably, the assessment and quantification of both has been endorsed as the gold standard for assessing the physiology of stress (Kivlighan & Granger, 2006). However, in contrast to the non-invasive nature of collecting saliva to be assayed for C, measurement of the sympathetic

branch of the stress response requires blood sampling and/or sophisticated software (as described above). Logistical issues can make these measurement approaches impractical in most competitive situations (Kivlighan & Granger, 2006). Recently however, a growing body of research reports that salivary α-amylase (sAA) – measured using the same saliva sample as C – is responsive to stress and supports its validity as a marker of sympathetic activity (Nater, et al., 2006; Nater, et al., 2005; Kivlighan & Granger, 2006; Granger, et al., 2006)

The primary role of sAA is to begin digestion of complex starches, sugars, and carbohydrates (Lebanthal, 1987) and is key for extracting caloric value from foods. Thus, at an applied physiological level, it makes sense that sAA would increase during periods of intense energy use and remain elevated long after the event so that energy stores could be replenished efficiently (Nater & Rohleder, 2009). This relationship has been supported by a number of studies examining the effects of sport and exercise on sAA, and in general reveal increased levels. These include running and bicycle exercise tasks (Chatterton, Vogelsong, Lu, Ellman, & Hudgens, 1996), cross-country (Nexo, Hansen, & Konradsen, 1988), marathon (Ljungberg, Ericson, Ekblom, & Birkhed, 1997), triathlon (Steerenberg, van Asperen, Van Nieuw Amerongen, Biewenga, Mol, & Medema, 1997) and 60-min cycle races (Walsh, Blannin, Clark, Cook, Robson, & Gleeson, 1999) and a taekwondo competition (Chiodo, Tessitore, & Cortis, 2011). In another study, the correlation between sAA and the anaerobic threshold obtained from a treadmill exercise test was $r = 0.93$ (Calvo, et al., 1997), and a study examining the impact of exercise on a 2-km rowing ergometer on sAA levels (Kivlighan & Granger, 2006) showed increased levels after exercise which were also positively associated with performance – that is varsity athletes had higher levels than novice athletes (105.42 U/ml ± 60.67 *vs.* 56.14 U/ml ± 39.46 respectively). Finally, Klein *et al.,* (2010) supported

these results, reporting increased sAA levels after consumption of caffeine, which is known to stimulate sympathetic activation.

The association between sAA and the SNS was first described by Chatterton and colleagues (Chatterton, Vogelsong, Lu, Ellman, & Hudgens, 1996; Skosnik, Chatterton, Swisher, & Park, 2000). Their studies showed that levels of sAA increased under both physically (i.e. exercise, heat and cold stress) and psychologically (i.e. written examinations) stressful conditions and that sAA concentrations were associated with norepinephrine (NE) change in response to stress (Chatterton, Vogelsong, Lu, Ellman, & Hudgens, 1996). This pattern of evidence appeared to support a link between the release of catecholamines into the bloodstream and release of α-amylase from the salivary glands during sympathetic activation. However, while more recent studies corroborate that sAA responds to physical and psychological stress, they suggest that it relates to sympathetic tone or adrenergic activation more generally, reporting little or no correlation with NE (Nater, et al., 2005; Nater, et al., 2006). Thus, whereas considering sAA as a correlate to the sympathetic component of the stress response seems reasonable based on the available data, using sAA as a specific or direct marker of NE appears less appropriate (Kivlighan & Granger, 2006; Nater & Rohleder, 2009). Furthermore, sAA's use as a marker of training stress is still relatively novel and thus more studies are required to fully elucidate how it can be used to acutely tailor training programmes (e.g., (Kivlighan & Granger, 2006)).

2.27.3 Salivary Immunoglogulin A

A "J-shaped" relationship between the volume of physical activity and susceptibility to upper respiratory tract infections (URTI) has been proposed (Nieman, 1994). That is, both low and

high volumes of exercise (although more so the latter) increase risk. The incidence of URTI's is associated with a reduction in salivary Immunoglogulin A (SIgA) levels (Neville, Gleeson, & Folland, 2008; Libicz, Mercier, Bigou, Le Gallais, & Castex, 2006; Novas, Rowbottom, & Jenkins, 2003; Gleeson, McDonald, & Pyne, 1999) – antibodies that play a vital role in mucosal immunity, forming the first line of defence to viral pathogens entering the body through mucosal surfaces. As such, this biomarker can be used to identify an athlete that is at risk of illness and infection if the training load is not acutely reduced. For example, Neville *et al.,* (2008) found that when SIgA concentration dropped below 40% of an athlete's mean healthy sIgA levels, they had a one in two chance of contracting an URTI within 3 weeks. While a decrease in SIgA is common following prolonged strenuous exercise, it usually recovers within 24-hours (Bishop & Gleeson, 2009). However, with continued high volume loads and insufficient rest, there is likely to be a chronic suppression of mucosal immunity lasting 7 days or more (Bishop & Gleeson, 2009), in which an "open window" is presented and the athlete is more susceptible to URTI's (Pyne & Gleeson, Effects of intensive exercise training on immunity in athletes, 1998). Furthermore, given IgA's circadian rhythm, exhibiting a morning nadir and rising throughout the day (which is also in contrast to that of cortisol), it may be prudent for athletes who are returning to training after injury or illness, or following an intensive training schedule, to consider the avoidance of early morning training sessions (Dimitriou, Sharp, & Doherty, 2002).

The use of SIgA analysis in sport is growing with several longitudinal studies, examining cross-country skiers (Tomasi, Trudeau, Czerwinski, & Erredge, 1982), triathletes (Libicz, Mercier, Bigou, Le Gallais, & Castex, 2006), swimmers (Gleeson, McDonald, & Pyne, 1999; Gleeson, McDonald, & Pyne, 2000) kayakers (Mackinnon, Ginn, & Seymour, 1993) distance runners (Mackinnon & Hooper, 1994), football players (Fahlman & Engels, 2005) and rowers

(Neville, Gleeson, & Folland, 2008), acknowledging that during periods of heavy training, athletes experience immunodepression, which is manifested by decreased levels of SIgA. While this mode of assessment is rather expensive, Neville *et al.,* (2008) did correlate sIgA concentrations with a simple three-scale fatigue rating questionnaire which asked "how rested do you feel?" the possible answers were (1) "worse than normal," (2) "normal," or (3) "better than normal." Option one indicated significantly lower SIgA concentrations than the other two and is indicative of an athlete at risk. In such circumstances, the athletes should have their training load reduced and perhaps should be rested altogether. It also goes without saying that good hygine must also be maintained at this time.

2.27.4 Methodological issues of salivary analysis

To fully appreciate the issues concerning validity and reliability of salivary analyte levels, it is necessary to discuss the collection process for saliva, and for sAA in particular, saliva and the saliva glands themselves.

There are three major salivary glands on each side of the face: the parotid, submandibular, and sublingual glands. In addition there are numerous minor glands in the submucosa underlying the lip, cheeks and palate (Humphrey & Williamson, 2001), all contributing to salivary out-flow and forming part of the digestive tract. The mixture of fluids derived from different glands is called ''whole saliva'', whereas the fluid secreted by single glands is called ''duct saliva''. The constant flow of saliva from the mouth into the gut has a protective function, transferring food debris and exogenous and possibly noxious agents for example.

When analyzing sAA, the collection of unstimulated "whole saliva" (see (Navazesh, 1993)) is regarded as best practice and in essence, involves participants drooling (Strazdins, Meyerkort, Brent, D'Souza, Broom, & Kyd, 2005) or "spitting" (Navazesh, 1993; Navazesh & Kumar, 2008) into a test tube; here, most saliva (~ 65%) is derived from the submandibular glands. However, under stimulation (i.e., of mechanoreceptors in the mouth during chewing), the contributions of each gland changes, with the parotid contributing more than 50% of total salivary secretions (Humphrey & Williamson, 2001). This is an important point as parotid saliva contains a 4—10-fold higher α-amylase concentration than submandibular saliva (Veerman, van den Keybus, Vissink, & Nieuw Amerongen, 1996). Furthermore, chewing increases glandular secretion independent of central regulation, i.e., the neural effects caused by stress (Garrett, 1987). As sAA is a digestive enzyme, this heavily influences its secretion. Therefore, sAA studies using saliva collection methods involving chewing may invalidate the data given that these local reflexes could modify or over-rule the central SNS effects on sAA release (Bosch, Veerman, de Geus, & Proctor, 2011). Bosch *et al.,* (2011) nicely compare this to the effects of changing posture on HR, which similarly induce autonomic reflexes that independently alter HR.

When analysing sAA it is also important for researchers to consider salivary flow rate. For example, while sympathetic stimulation dictates sAA synthesis within the salivary glands, it is the parasympathic activity that largely controls salivary flow rate from them. Therefore only the amount of amylase that is secreted per unit of time (as oppose to its concentration) is directly related to the extent of sympathetic activity (Proctor & Carpenter, 2007). As such, if sAA is to be regarded as a valid measure of sympathetic activity, then the parasympathetic effect on salivary flow rate (i.e., the time taken to produce a particular quantity of saliva) is a confounding factor that needs adjustment. Similarly, increases in saliva flow rate (i.e.

immediately after eating or drinking) may lead to a diluting effect and an obvious decrease in SIgA levels; also, decreases in saliva flow rate (anxiety, high-intensity exercise) may lead to a concentrating effect and apparent increases in SIgA concentrations (Bishop & Gleeson, 2009). For both these analytes therefore, salivary flow rate must be recorded and results expressed as a function of time (Rohleder, Wolf, Maldonado, & Kirschbaum, 2006):

*E.g., units sAA activity/mL * mL/min = Units sAA activity/min*

Unlike sAA and SIgA, flow rate does not affect the recording of T and C levels. As such, chewing an original flavour sugarless gum is a viable sample collection technique when a large volume of saliva is required (>2 ml; but researchers should allow athletes to chew for at least 3 min before beginning to collect the sample) (Granger, Schwartz, Booth, & Arentz, 1999) or when collection becomes increasingly difficult due to prolonged exercise for example. Here, the physical activity increases sympathetic activation with concomitant parasympathetic withdrawal and thus reduced saliva flow rate (Papacosta & Nassis, 2011). This would likely be coupled with dehydration and hyperventilation causing evaporative loss of saliva, all increasing the time required to collect samples. Furthermore, when collecting saliva, it is important to note that T and C levels are sensitive to the effects of blood leakage into the mouth caused by micro-injury e.g., via teeth brushing, open sores and injury (including that caused by wearing a mouth-guard). Therefore questions around these should be asked, including ensuring they have not brushed their teeth within 45 minutes. Because there is more T and C in blood, as this also contains those bound to their carrier protein, results will appear artificially high.

Finally, rather than the passive drool method, some researchers use cotton sponges (or swabs) such as the salivette to collect saliva. These are more convenient to use, for example during competitions, exercise tests and also with children. Also, due to the buffering agent, they can be stored at room temperature (4 – 37°C) for up to 12 months. In contrast, when collected using a vile, samples must be stored at -80 °C within 6 hours to avoid bacterial growth interfering with antibody binding. For example, research into T have shown that storage for one week at 4°C (refrigerator) increased T levels by 20%, and at -20°C and -40°C (freezer) for six months, decreased levels by 18 and 6% respectively (Granger, Shirtcliff, Booth, Kivlighan, & Schwartz, 2004). Despite these benefits, collections via swabs are often thought to introduce large measurement error to a number of salivary analytes, including sAA and (discussed below) SIgA (Strazdins, Meyerkort, Brent, D'Souza, Broom, & Kyd, 2005; Beltzer, Fortunato, Guaderrama, Peckins, Garramone, & Granger, 2010). This in part may be due to the difficulties in reliably assessing salivary flow rate, whereby there is an assumed time to collect a certain volume of saliva (typically 0.25 ml of saliva in 1 min; (DeCaro, 2008)) before the material is fully saturated (see discussion by (Beltzer, Fortunato, Guaderrama, Peckins, Garramone, & Granger, 2010; Bosch, Veerman, de Geus, & Proctor, 2011)). Also, given the varying contribution of the saliva glands to whole saliva, the placement of the salivette is important and must be standardised. In general, it is recommended that it be placed in the centre of the tongue for consistency of collection.

In conclusion, the advantage of saliva monitoring is the non-invasive, stress free (noting that you are measuring this and thus do not want to induce it by virtue of the test protocol) method that can be used by athletes at home or at competitions to assess immunological and endocrinological stress to avoid overtraining and upper-respiratory tract infections (Papacosta & Nassis, 2011). There still needs to be a unified standardized collection procedure to ensure

accuracy of data when using some devices to ensure reliability (Groschl, Kohler, Topf, & Rauh, 2008). When applying this method into the field, the cost benefit analysis needs to be addressed.

2.28 HEART RATE: RESTING, SLEEPING, RECOVERY AND VARIABILITY

Exercise stress has also been assessed by virtue of resting HR, sleeping HR, HR recovery (HRR) and HR variability (HRV). To understand the premise of these, it is first important to identify the regulation of HR. HR is regulated by the autonomic nervous system (ANS) whereby the sinoatrial node is under the influence of the sympathetic and parasympathetic nervous system. The latter slows HR via the vagus nerve by releasing the neurotransmitter acetylcholine, while the former increases HR by releasing NE. These too work together to modulate HR depending on the environmental demands and stimuli. Under stressful situations (such as fight or flight) or if the body is in a state of recovery, the release of catecholamines would maintain a relatively high HR. Should this continue, with the chronic overwork resulting in OT and subsequent adrenal gland exhaustion, HR may fall as the parasympathetic nervous system then predominates. As such, this relationship allows for the deduction that rises in resting HR or sleeping HR may be indicative of residual training stress and place the athlete on the continuum for OT; of note, sleeping HR is considered more reliable as the athlete is less influenced by the external stimuli that would otherwise affect HR and distort results (Lambert & Borresen, 2006). In actuality, the review of Lambert & Borresen (2006) revealed that resting HR is too varied to be of use and while sleeping HR is more reliable, an individual variation in minimum HR of up to 8 beats/min (Waldeck &

Lambert, 2003) is too high to provide any prognostic value in identifying fatigue in athletes. So again, if this is to be used, it must be used in concert with other measures of fatigue.

Using this principle, HRR following an exercise bout can be used to assess residual fatigue, or rather, ANS functioning; at the cessation of exercise there should be parasympathetic reactivation and sympathetic withdrawal. A reduced HRR would suggest that an athlete is unable to cope with the current training load, is accumulating fatigue and ultimately, is now not positively responding to training stimuli (Lambert & Borresen, 2006; Lamberts, Swart, Capostagno, Noakes, & Lambert, 2010). Also, endurance performance has been shown to improve most in athletes who can show continual increases in HRR (Lamberts, Swart, Capostagno, Noakes, & Lambert, 2010). HRR is calculated as the absolute difference between HR at the completion of exercise and HR following 60 s of recovery. Testing protocols can be implemented to assess recovery following high intensity intervals (e.g., see (Lambert & Borresen, 2006; Lamberts, Swart, Capostagno, Noakes, & Lambert, 2010)) or steady state submaximal running (e.g., the 5'-5' test of (Buchheit, 2008; Buchheit, 2008b; Buchheit, et al., 2010), whereby athletes perform at a constant absolute workload (Lambert & Borresen, 2006; Lamberts & Lambert, 2009) or work at a constant submaximal heart rate (Lamberts, Lemmink, Durandt, & Lambert, 2004; Lamberts, Rietjens, Tijdink, Noakes, & Lambert, 2010). However, tests using a constant absolute workload can be compromised when the training status of an athlete changes (on account of changes in relative intensity) (Lamberts, Rietjens, Tijdink, Noakes, & Lambert, 2010; Short & Sedlock, 1997), therefore it has been recommended that testing should follow high intensity exercise at an intensity of 85 – 90% HRmax. This is associated with the lowest day-to-day variation in HR (6 ± 2 bpm); also measuring after one minute is also more reliable than after 2 minutes (Lamberts, Maskell, Borresen, & Lambert, 2011). Caution has been advised with regards to interpreting

data on HRR as research still questions its usefulness due to this variability (Bosquet, Gamelin, & Berthoin, 2008). Lambert *et al.,* (2011) advise that a test-to-test change in HRR of > 6 bpm can be regarded as a meaningful change under controlled conditions.

HRV is a simple and reliable tool for the evaluation of ANS functioning and was originally used within the field of medicine for the diagnosis of various diseases, e.g., myocardial infarction; it is now quite routinely used in sports for the assessment of fitness and fatigue. HRV assesses the time interval between the RR intervals (Figure 2.8), which due to respiration will lengthen with expiration (consequent to parasympathetic tone) and shorten (due to sympathetic tone) with inspiration. A high variability (calculated as the standard deviation of all normal RR intervals) is therefore considered healthy, while low variability may be due to a dysfunction in the ANS and in the context of sport, may relate to the accumulation of fatigue. The RR intervals are measured during 5 min of passive rest (due to the profound influence of respiration) via ECG, usually at a sampling rate of 1000 Hz, thus providing an accuracy of ± 1 ms. More recently however, commercial software has become available to assess HRV via HR monitors (e.g., see (Lopes & White, 2006)) and wireless chest straps (measured over 10min). These, unlike fingertip or ear lobe assessment, are considered valid and reliable alternatives (Achten & Jeukendrup, 2003). However, there are equivocal findings regarding HRV, which may be due to methodological inaccuracies and large day-to-day variation in HRV recordings (Al Haddad, Laursen, Chollet, Ahmaidi, & Buchheit, 2011). As such, it is recommended that values are averaged over 7 days (Plews, Laursen, Kilding, & Buchheit, 2012; Plews, Laursen, Kilding, & Buchheit, 2013) or at least 3 in trained athletes and 5 in recreational athletes (Plews, Laursen, Kilding, & Buchheit, 2012) to improve validity. Given this requirement, athlete compliance must also be addressed, noting that only 14 out of the 40 athletes in the study by Bucheit *et al.,* (2010) collected

enough morning resting HRV samples to merit study inclusion. Data collection usually involves collection via wireless chest strap monitoring, with the athlete in a supine position; data is collected over an 8 min period, with only the final 5 min analysed (Plews, Laursen, Kilding, & Buchheit, 2012; Plews, Laursen, Kilding, & Buchheit, 2013). Achten and Jeukendrup (2003), using Figure 2.9, provide example calculations involved in formulating HRV. The average RR interval in their example is 925 ms with a SD of 40 ms. They then calculate the root mean square of successive differences (i.e., the difference between adjacent intervals are squared and the mean is calculated), which is 62.6 ms and also express the percentage of all RR intervals that differ by more than 50ms; of the 11 there are 6 giving a score of 67%.

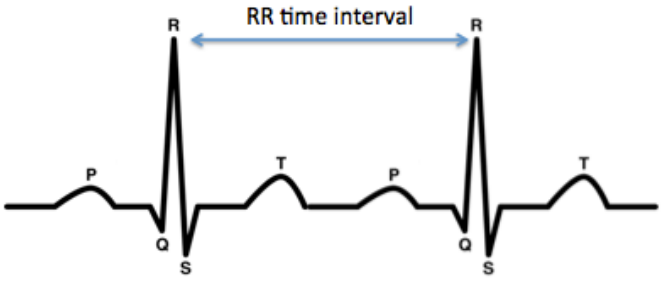

Figure 2.8 Schematic representation of an RR time interval. The P wave represents atrial depolarization, the QRS complex represents ventricular depolarization and the T-wave represents ventricular repolarization. The RR time intervals (measured in milliseconds) will continually change due to the influence of respiration.

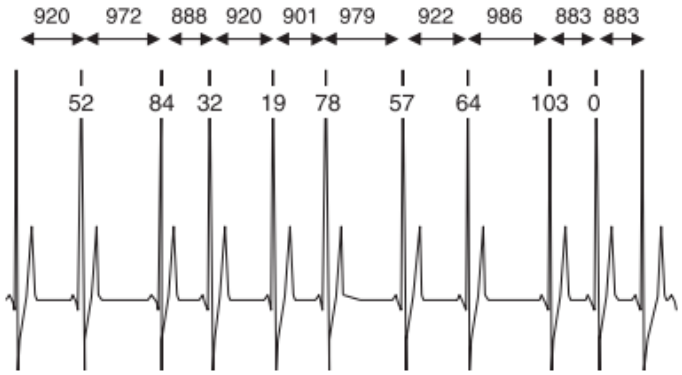

Figure 2.9 The time interval and difference between adjacent RR intervals; the latter provides an index of cardiac vagal (parasympathetic) tone. Example provided by Achten and Jeukendrup (2003)**.**

The use of HRV in athletes appears useful when assessed alongside additional measures. Studies have reported changes in the catecholamine concentrations at rest or during exercise when an athlete has completed a high training volume phase which could justify the potential usefulness of HRV in the monitoring of athletes (Bosquet, Gamelin, & Berthoin, 2008). Along with this, HRV shows a tendency towards progressively lower parasympathetic and higher sympathetic drivers over a period of cumulated training loads which could help with the planning and monitoring of training programs (Pichot, et al., 2000; Aubert, Seps, & Beckers, 2003). The time course of HRV recovery (return to homeostasis) is a function of exercise intensity and modality (Gladwell, Sandercock, & Birch, 2010), however there are numerous other factors that lead to variations in the recovery of the ANS (Aubert, Seps, & Beckers, 2003). There is a strong need for research on the mechanism exerted by the ANS on cardiovascular function to aid in the monitoring of athletes. Currently, HRR is considered a more reliable method and better associated with recently applied training loads; HRV indices are mainly associated with long-term changes in the ANS (Buchheit, Papelier, Laursen, & Ahmaidi, 2007; Buchheit, Millet, Parisy, Pourchez, Laursen, & Ahmaidi, 2008).

2.29 CONCLUSION AND PRACTICAL APPLICATIONS

The causes and mangement of OT have been addressed by researchers for over 30 years. When it comes to management and monitoring interventions, it is clear that there is no one solution to address this. Also, what works for one athlete or club, will not necessarily work for another and there will thus be a trial and error process while procedures are apadted to the practicalities of the environment. Due to the multifaceted nature of stress and fatigue, several protocols should be used to asses each of its components; this will help in the interpretation of data and reduce the liklihood of incorrect conclusions.

In essence, to manage fatigue and enhance recovery, there are four princinciple questions a coach needs to assertain on a daily basis (Lambert & Borresen, 2006). Table 2.4 identifies these along with the testing methods available to answer them. Based on the review herein, and with practicality and cost in mind, the following tests are suggested (the timings of each test should be consistent and collected on a daily basis if possible):

1. To quantify the intensity of the session the sRPE is used.
2. To assess the cumulative stress of training, a combination of the DALDA questionnaire and sport-specific tests be used. However, some may prefer the SQF due to its speed and simplicity, but this would mean removing the source of stress, which may provide useful information. Over time, and using validated criteria for recovery, e.g., sleep, muscle soreness and nutrition, the sport science team may also develop their own.
3. To measure the efficacy of recovery practices the TQR questionnaire is used.

Table 2.4. The four principle questions, along with the testing methods available to answer them, that a coach should ask in order to manage fatigue and enhance recovery (Lambert & Borresen, 2006).

1. How hard did the athlete find the session?
• RPE
2. How hard was the session?
• TRIMP
• sRPE
3. How did the athlete recover from the session?
• TQR, RESTQ-Sport
4. How is the athlete coping with the cumulative stress of training?
• Questionnaire: BRUMS; DALDA, SQF
• HR_{rest}; HR_{sleep}; HRR; HRV
• Blood/salivary analysis: T; C; T:C; IgA
• Sport-specific performance test (e.g., measuring speed, agility strength and/or power)

Chapter 3

GENERAL METHODS

3.1 INTRODUCTION

This thesis contains four progressive studies designed to optimise physical preparation in Olympic fencing. In doing so, the initial studies (study one and two, chapter four and five respectively) examine the physical characteristics that underpin the fundamental movements of fencing; these are lunging, CODS and the maximal and repetitive combination of these across a bout. Such information can inform and justify the strength-training programme undertaken by these athletes. The final two studies (study three and four, chapter six and seven respectively) examine the metabolic demands of competition and thus the appropriate training and integration of these exercises, within the fencers' programme. It is expected that this information would inform the fitness and conditioning element of physical training, as well as assessing the fencers' ability to cope with training load and programme structure, providing a measure from which the validity of these can be critiqued.

All studies were undertaken at location, at either the national training centre or at the competition venue. Participants comprised of athletes from the world-class talent programme (formerly the National Academy) and the world-class podium potential programme. The latter squad were full-time athletes based at the national training centre. Participation in these studies was considered part of all athletes training requirements. Experimental studies one and two used a mix of athletes from both pathways, whereas studies three and four used only world class podium potential athletes. Ethics for all studies was approved by the London Sport Institute at Middlesex University and the Performance Director of British Fencing.

Identified below are the testing protocols used within the methods of two or more studies; these protocols are consistent in their use.

3.2 ANTHROPOMETRIC DATA

Body mass was measured to the nearest 0.1 kg with an accurately pre-calibrated electronic weighing scale (Seca Alpha 770, Birmingham, UK). Participants were instructed to stand in the centre of the weighing scale's platform, barefoot and with minimum clothes (Eston & Reilly, 2009). Stature was measured to the nearest 0.1 cm with a stadiometer (Seca 220, Birmingham, UK). Participants were asked to stand barefoot in an erect position with heels together, arms hanging relaxed at sides and their upper back, buttocks and cranium against the stadiometer They were also instructed to fully inhale, stretch up and orientate their head in the Frankfort plane upon measurement (Eston & Reilly, 2009). The measurement was taken as the maximum distance from the floor to the highest point (vertex) on the skull.

3.3 LOWER-BODY POWER

Jump height was typically measured in the countermovement jump (CMJ) and single leg-countermovement jump (SLCMJ) for both front (or lead) and back legs. SLCMJ scores were used to identify any asymmetries between legs. Reactive strength index (RSI) was measured following a drop jump from a box height of 30cm. Typically this is measured at multiple heights (also 45, and 60 cm) (Flanagan & Comyns, 2008) but without appropriate technique, higher boxes can yield unreliable results and can be an injury risk. During the test, fencers were instructed to minimize ground contact time and then jump as high as possible. The RSI was calculated as flight time in milliseconds divided by ground contact time in milliseconds.

For all jumps (drop jump, CMJ, SLCMJ), fencers were instructed to keep their hands in contact with their hips for the duration of the test. Any movement of the hands away from the hips would have resulted in the jump being disqualified. Following take-off, fencers were also instructed to maintain full extension until contact had been made with the floor upon landing. All scores were measured using an optical measurement system (Optijump, Microgate, Italy) and recorded to the nearest 0.01cm (or to two decimal places in the case of RSI). The standing broad jump was measured using a flexible tape measure, placed along the ground. Fencers had to jump as far forward as possible, keeping their hands on their hips as per other jump tests. If the fencers fell forward at landing, causing their feet to change position, the jump was disqualified. Scores were recorded to the nearest 0.1 cm, and in line with the heel of the foot furthest back. For all tests of lower-body power, three trials were conducted for reliability analysis, with the highest score used for analysis.

During competition testing (study three, chapter seven) however, jump tests were analysed using a force plate (type 92866AA, Kistler Instruments Ltd., Hook, United Kingdom; sampled at 1000 Hz) and jump height calculated using the impulse-momentum method (Linthorne, 2011). This is considered the most accurate calculation of flight height, but is dependent on the correct selection of an instant before the start of the jump, where the jumper is stationary and the vertical ground reaction force (VGRF) is equal to the jumper's body weight; an error of 10 N in selecting the bodyweight of the jumper produces an error in the flight height of 2–3 cm (Linthorne, 2011). Furthermore, the flight height calculated using the flight-time method is usually ~ 2 cm greater than that calculated using the impulse–momentum method, because the jumper is usually lower at landing than at take-off (Linthorne, 2011).

During jump trials, the athlete remained stationary on the plate for 3 s before jumping (enabling an accurate measurement of bodyweight). VGRF data was then averaged across this period and the jump was deemed to start when this value was reduced by 5 standard deviations (Owen, Watkins, Kilduff, Bevan, & Bennett, 2004). For all analysis, the athlete's bodyweight was subtracted from the VGRF values. The vertical force impulse between the start of the jump and take-off was then calculated using the trapezoidal method (using intervals equal to the sample width) and in turn used to calculate take-off velocity (Owen, Watkins, Kilduff, Bevan, & Bennett, 2004). Jump height was finally calculated using $v^2 = u^2 + 2as$.

Force plate assessment enabled additional analysis including the calculation of peak power and peak rate of force development (PRFD); the latter was calculated as PF divided by time to PF. Instantaneous power was determined as follows:

Power (W) = VGRF (N) × vertical velocity of CG (m/s)

Velocity of the athlete's centre of gravity (CG) was calculated by dividing each strip area of impulse by the athlete's mass, which was then added to the CG's previous velocity to produce a new velocity for that time interval (Crewther, Kilduff, Cunningham, Cook, Owen, & Yang, 2011). The CG velocity was taken to be zero at the point identified as the start of the jump.

Rate of force development (RFD) is becoming an increasingly popular assessment. Strong correlations have been shown between isometric PRFD and peak force (as measured during the isometric mid thigh pull) and clean-and-jerk (r = .64, r = .69) and snatch (r = .93, r = .79) performance in competitive female weightlifters (Haff, Carlock, & Hartman, 2005). West *et al.,* (2011) also reported significant inverse correlations between isometric force at 100 milliseconds (r = –.68), isometric PRFD (r = –.66), and 10-m-sprint performance in Rugby

League athletes. Jensen and Ebben (2007) also suggest the use of the eccentric RFD during the landing phase of jumping activities to quantify the intensity of plyometric training; this is regarded as a more sensitive measure than GRF's. Finally, Wilson et al., (1995) examined the concentric (via squat jump) and eccentric (via countermovement jump) RFD in jumping and found this to better relate to sprint performance than isometric RFD tests. In particular the concentric RFD was superior, with the authors suggesting that while eccentric forces are higher in jumps involving the stretch-shortening cycle (including during sprints), the velocity over which this phase occurs is much slower than its equivalent when sprinting. They further suggest that because strength capacity eccentrically is superior to concentric contractions (~ 1.3 times greater), concentric strength may be the limiting factor. That said, force measured at 30 ms and PRFD, concentrically and eccentrically, had coefficients of variation of > 10%; measures taken at 30 ms were most unreliable (CV > 40%); unfortunately reliability data was not provided in the study by Jensen and Ebben (2007). In summary, given the validity of the RFD measure to sports performance, its assessment is warranted but investigators should take caution when measuring this variable dynamically as the faster the movement the greater the error, especially when measuring at shorter time intervals (e.g., 30 ms).

3.3.1 Data Filtering

Where force plate analysis was employed (studies one and three, chapters four and five respectively), data was filtered using a Butterworth fourth-order zero lag low-pass filter, with a cut-off frequency determined by residual analysis (Winter, 2009). A residual analysis identifies the difference between filtered and unfiltered signals across a wide range of cut-off frequencies. A low-pass filter passes signals with a frequency lower than the designated cut-off frequency; signals with frequencies above this are attenuated. The final process requires the correction of distortion created by the filter itself, and involves passing the data through

the filter twice; once in the forward direction and once in the backward direction. This results in the application of a fourth-order, zero-lag filter (Enoka, 2008).

3.4 CHANGE OF DIRECTION SPEED

The CODS was measured using a 4-2-2-4 m shuttle. For this, fencers started behind one set of timing gates (Brower timing systems, Utah) set at hip height. Using fencing footwork, they travelled as fast as they could up to a 4 m line, ensuring their front foot crossed the line, they then travelled backwards ensuring the front foot crossed the 2 m line. Again they travelled forward to the 4m-line, before moving backwards past the start line. The test was carried out on a metal, competition fencing piste to increase validity. The test was immediately stopped if the athlete used footwork deemed by the fencing coach to be unrepresentative of proper form, if the beam was broken at the start or finish line with any part of their body other than their hips, or if the athlete failed to pass either line with their toes or lunged in order to reach the line. Three trials were performed with the best score used in the analysis. During pilot testing, two other CODS tests were initially used. The first involved a shuttle sequence of 3-3-3-3-3-3 m (i.e., 3 m out to a line, 3 m back and repeat three times) and the second a shuttle sequence of 2-4-2 m. However, it was found that because fencers continually return to the start position where the beam of the light gate is broken, reliability was affected, resulting in intraclass correlations of $r < 0.8$. For this reason, the 4-2-2-4 m shuttle, where the beam was only broken at the start and finish of the test was developed and used for investigation.

3.5 Heart Rate, Blood Lactate and Session Rating of Perceived Exertion

In studies three and four (chapters seven and eight respectively), during competition and training respectively, fencers wore heart rate (HR) monitors, had blood lactate (BL) measures recorded and reported session ratings of perceived exertion (sRPE). HR was measured using the Polar team^2 Pro (Warwick, United Kingdom) as per manufacturer instructions (see: http://www.polar.com/us-en/support/User_Manual_for_Polar_Team2_Software_in_English), with data analysed to reveal average HR, maximum HR and time spent above 80% of maximum HR in each bout and for each type of training mode (e.g., conditioning, sparring and footwork). BL was measured via finger prick of the non-fencing hand using a Lactate Pro and again according to manufacture guidelines (see: http://www.lactatepro.com.au/lactatepro/USING.html). BL measures were taken 5 min pre and post bout and exercise session, with scores of the latter again separated to differentiate modality (e.g., conditioning, footwork, sparring). During study three, all scores were averaged across the two analysed competitions, and separated to define pool bouts (first to 5 hits) and elimination bouts (first to 15 hits). However, scores were also analysed to determine if increases were noted following each bout, as the competition progressed. During competition and training, again separated by bout and exercise mode respectively, sRPE scores, using the Borg category ratio10-point scale (Figure 3.1) (Borg, 1982), were taken with the score multiple by duration (min) to reveal the training load (measured in arbitrary units; AU). Scores were provided by athletes 5 min post bout or exercise.

	Session RPE
0	Rest
1	Really easy
2	Easy
3	Moderate
4	Sort of hard
5	Hard
6	
7	Really hard
8	
9	Really, really hard
10	Just like my hardest race

Figure 3.1 The session RPE scale (Foster, Daines, Hector, Snyder, & Welsh, 1996)

3.6 SALIVARY ANALYSIS

In study three (chapter seven), athletes provided saliva samples which were later analysed for concentrations of testosterone, cortisol, immunoglobulin A and alpha amylase. The collection process and subsequent analyses were carried out according to manufacturer instructions (Salimetrics, Suffolf United Kingdom) with detailed procedures for each available in appendix D. In summary, unstimulated saliva was collected via passive drool into a cryovial for analysis of all analytes (Bishop & Gleeson, 2009; Proctor & Carpenter, 2007). In order to preserve the integrity of samples, fencers were instructed to avoid food, fluid (except water) and brushing their teeth, one hour before collection; 10 minutes prior to collection, fencers had to rinse out their mouth with water (Groschl, Kohler, Topf, & Rauh, 2008). After collection, samples were immediately frozen at -20°C (commercial freezer, where they remained for 2 weeks), before being transported to and stored at -80°C until analysis (Granger, Shirtcliff, Booth, Kivlighan, & Schwartz, 2004). Once thawed, analytes were measured using enzyme-linked immunosorbent assay (ELISA) – a test that uses antibodies to

detect the presence of antigens via a colour change. The analyte within the standards and samples compete with that conjugated to horseradish peroxidase for the antibody binding sites on a microtitre Plate. After incubation, unbound components are washed away and then bound analyte enzyme conjugate is measured by the reaction of the horseradish peroxidase enzyme to the substrate tetramethylbenzidine (TMB); this reaction produces a blue color. A yellow colour is formed after stopping the reaction with an acidic solution. The optical density is read on a standard plate reader at 450 nm. The amount of analyte enzyme conjugate detected is inversely proportional to the amount of analyte present in the sample (Chard, 1990).

3.7 STATISTICS

All studies involved statistical analysis, examining normality, reliability, relationships and/or differences. These are discussed in turn below.

3.7.1 Normality

The normal distribution is one of the most used probability distributions in statistics and is what defines parametric tests (i.e., those tests that make assumptions about the population from which the data was drawn). Normality is generally checked via the kolmonogorov-Smirnov or Shapiro-Wilk test, but can also be assessed via z-scores as described by Field (2013). Normality is one of four assumptions of parametric data, the other three being homogeneity of variance (i.e., variance across all tested groups from the population is similar), data is measured at least at the interval level and is independent (i.e., data from different participants are not related). Results from “normal” data can also be applied to other

populations making the findings from this thesis, applicable to others working within the sport of fencing.

3.7.2 Reliability

After checking for normality, reliability is then assessed. Reliability refers to the consistency or agreement of a test or measurement, and is a statistic that should be calculated and acknowledged as part of the overall findings. All studies reported Intraclass correlation coefficients (ICC) and study four (for purpose of salivary analysis) also used the coefficient of variation (CV). The ICC is a relative measure of consistency (i.e., scores are ranked), while the CV is an absolute measure, providing an indication of the precision of a score and the degree to which repeated measurements vary for individuals.

No definitive agreement exists in identifying the varying thresholds of ICC value, for example, what constitutes as "poor", "moderate" or "high" reliability. Typically, most research uses 0.8 as an acceptable value for ICC reliability, but according to Vincent (1999), ICC values of > 0.9 represent a high level of agreement, between 0.8 and 0.89 represent moderate agreement and values < 0.8 represent questionable agreement for physiological data. For the CV, the threshold tends to be $\leq 10\%$ to denote acceptable reliability.

3.7.3 Correlations

All studies reported correlations, which describe possible relationships. The correlation assumes that if we affect one variable, then we will affect the other. The strength of that relationship is denoted by the '*r*' value, ranging from -1 to 1, with 0 indicating no

relationship. According to Cohen (1988), correlation coefficients of .10 are "small," .30 are "medium," and .50 are "large" in terms of magnitude of effect sizes (effect size being a measure of the strength of the relationship between two variables and is discussed below). These descriptions can be further augmented with 0.7 and 0.9 for "very large" and "extremely large" (Hopkins, Marshall, Batterham, & Hanin, 2009). Furthermore, the r value can be squared to denote the coefficient of determination (r^2). This is a measure of the amount of variability in one variable that is explained by another and is usually expressed as a percentage (by multiplying by 100). For example, if the correlation between strength and speed is r = 0.8, then r^2 = 64% (0.8 x 0.8 x 100). That is, 64% of the variability in speed is explained by the variability in strength. It also infers that 36% of the variability is accounted for by other variables.

3.7.4 Multiple Linear Regression

An extension of bivariate correlations is multiple linear regressions, which aims to predict a variable based on two or more variables; multiple linear regressions were used in studies one and two (chapters four and five respectively). Through the inclusion of additional variables, the model should be able to account for a greater percentage of variance in the outcome measure. Multiple linear regressions operates under the same assumptions as correlations, but also demands that multicollinearity is avoided, i.e., no pair of variables can be highly correlated (r = > 0.9), and there should be at least 20 cases (participants) for each independent variable. In sport science however, only 10 cases per variable is required (O'Donoghue, 2012).

3.7.5 Differences between Groups

To test differences between two groups, a *t*-test is used where the means of each group are compared. Where groups are independent of the other, independent samples *t*-tests are used and when comparing groups to themselves, a paired samples *t*-tests is used; the former was used in study two and the latter in study three and four. In determining whether a significant difference exists, the variability within each group, in addition to the mean, is taken into account, and as such, having a homogenous group is beneficial.

3.7.9 Effect sizes

In addition to reporting significant differences, it is also advised to report effect sizes (ES) – these are used in study 2. The ES is a measure of the magnitude of an observed effect, whereas the *t*-test just identifies whether one is different from the other. The ES is usually calculated using Cohen's *d* illustrated in equation one. An ES of 0.2 indicates a small effect, 0.5 indicates a medium effect and 0.8 a large effect (Cohen, 1988).

Equation 1.

$$d = (M_{group1} - M_{group2})/SD_{pooled}$$

$$\text{Where } SD_{pooled} = \sqrt{([SD^2_{group1} + SD^2_{group2}]/2)}$$

3.7.10 ANOVA

An ANOVA (analysis of variance) is used when examining differences between three or more means. Repeated measures ANOVA (as used in study three and four) looks at the same group on three or more occasions. Using an ANOVA is quicker than running several *t*-tests and makes reporting the findings easier should no difference be found. This method, by virtue of its post hoc tests, also helps guard against Type I errors, whereby the null hypothesis is wrongly rejected, i.e., you report a significant finding that does not exist (a Type II error is one where you wrongly accept the null hypothesis when you should have rejected it). Similar to the *t*-test, an ANOVA looks at the ratio of the between-samples variance to the within-samples variance (hence the name "analysis of variance"), and is called the F-ratio. For a one-way ANOVA (where there is only one dependent variable, e.g., just comparing speed times or strength scores), the variance of the dependent variable should be similar between the different samples being compared and is tested using Leven's test of homogeneity of variances. For repeated measures ANOVA, homogeneity of variance and covariance (i.e., a measure of how two variables change together) is tested using Mauchly's test of sphericity. Where differences are found, post hoc tests are used to investigate differences between individual pairs of groups. Normally in sport science, Bonferroni or Tukey's tests are used, the former is more conservative than the latter but some journals appear to favour one over the over; there are pros and cons of each. Effect sizes between pairs can be reported as per *t*-tests.

3.7.11 Statistical power

Studies should be preceded by calculating statistical power, which is a measure taken to ensure a study is capable of detecting an effect when one exists. Therefore, when statistical power is high, the probability of making a type II error is low. It is generally accepted that we should aim to achieve a power of .8, i.e., an 80% chance of detecting real effects. Commonly, this is ensured through having an adequate sample size, therefore before any research commences, investigators determine how many participants are required. The computations for this are available via software programmes such as G*Power (Field, 2013). Based on the work of Cohen (1992) using α = .05 and β (i.e., statistical power) = .8, then to be able to detect ES's of *r* = .1, .3 and .5, we would need sample sizes of 738, 85 and 28 respectively. Given the nature of this thesis however, sample size was dictated by the number of athletes on the British Fencing Programme.

3.8 STRENGTH AND CONDITIONING TRAINING

Fencers engaged in four to six S&C training sessions a week, generally two or three gym based sessions and the same for conditioning. Gym based sessions used a non-traditional approach to periodization, whereby the emphasis on strength and power regularly changed between sessions; this was on account of the frequency of competitions and the external commitments of fencers e.g., university and additional employment. Conditioning sessions focused on an "off feet" approach given the high impacts to the lower body within a highly repetitive movement pattern and the prevalence of associated injuries (see section 2.6 risk of injury). As explained in section 2.9 (repeat sprint ability), work to rest ratios were designed to induce high levels of BL, with the PCr system developed through increases in strength and

power by virtue of the gym sessions. Gym sessions and conditioning sessions typically rotated through as described in Table 3.1 and 3.2 respectively.

Table 3.1. Gym sessions for the development of strength and power

Session	Emphasis	**Details (sets x reps, rest period) -** load for strength exercises were at the max for that rep range, for power, the load varied.
1	Strength	a) Bask Squat or deadlift (4 x 4, > 4 min), b) stiff leg deadlift (3 x 6, > 3 min), c) roll-outs (3 x 10, 30 s)
2	Strength	a) Bench press, b) pull-ups (3 x 6, > 3 min), c) barbell bent over row (3 x 6, > 3 min), d) barbell shoulder press (3 x 6, > 3 min)
3	Strength	a) Split squat (3 x 6 each leg, > 4 min), b) Nordics (3 x 6, 30 s) c) cable rotations (3 x 10, 30 s)
4	Power	a) high pulls (5 x 3, > 4 min), b) jump to box (5 x 3, > 1 min), c) single leg jump to box (5 x 3 each leg, > 1 min), d) roll-outs (3 x 10, 30 s)
5	Power	a) Split snatch or split jerk (5 x 3, > 4 min), b) hurdle jumps (5 x 3, > 1 min), c) single leg hurdle jumps (5 x 3 each leg, > 1 min), d) angled barbell rotations (3 x 10, 30 s)

Table 3.2 Conditioning sessions for the development of the glycolytic system and associated buffer capacity

Session	Details (work x reps, rest period)
1	Wingate sprints (3 – 6 x 30 s, 30 s)
2	Sled pulls – loaded so fencers could only move at walking pace (30 m x 6, 30s)
3	Circuit: consisting of crash mat jumps (various) and medicine ball slams (8 x 30 s, 30 s)
4	Battle ropes – various (12 x 15 s, 15 s)
5	Rowing ergometer – (6 x 30 s ensuring to row >160m each rep, 30 s)

Chapter 4

STUDY ONE. PHYSICAL CHARACTERISTICS UNDERPINNING LUNGING AND CHANGE OF DIRECTION SPEED

4.1 INTRODUCTION

Fencing involves a series of explosive attacks, spaced by low-intensity movements with varying recovery periods, predominately taxing anaerobic metabolism (Wylde, Frankie, & O'Donoghue, 2013; Guilhem, Giroux, Chollet, & Rabita, 2014). The lunge is the most common form of attack, with around 21 per bout (Aquili & Tancredi, 2013) and 140 across elimination bouts (Roi & Bianchedi, 2008). Equally, change of direction speed (CODS) is fundamental to performance; during the elimination bouts of foil and epee, a fencer may cover as much as 1000 m and change direction around 200 times (Roi & Bianchedi, 2008). In sabre, where each point lasts around 2.5 s, there are a reported 7 changes in direction per 5-point bout (Aquili & Tancredi, 2013). As such, lunging and changing direction are the most prevalent actions performed, and well acknowledged as fundamental to success (Roi & Bianchedi, 2008; Tsolakis & Vagenas, 2010). Furthermore, Guilhem *et al.,* (2014) and Tsolakis *et al.,* (2010) noted that elite fencers are faster than non-expert fencers in both. It is clear therefore, that the physical characteristics that underpin these skills should be identified so that they may be developed as part of a fencer's training programme.

Quantitative data describing the physical determinants of the lunge are sparse and what is available has tended to focus on kinematic data that reveal technical points more relevant to the sports coach (Gholipour, Tabrizi, & Farahmand, 2008; Gutierrez-Davila, 2011; Gresham-

Fiegel, House, & Zupan, 2013; Stewart & Kopetka, 2005). Only Tsolakis and Vagenas (2010), Tsolakis *et al.,* (2010) and Guilhem *et al.,* (2014) have examined the relationship between anthropometric, physiological traits and lunging. The former two (using 18 females and 15 males from the Greek national team; sword not specified) looked at time of lunge as measured via four photocells placed at a lunge distance of 2/3-leg length. They found that lunge time was significantly ($p < 0.05$) correlated with body fat percentage ($r = 0.36$), dominant and non-dominant thigh cross sectional area ($r = 0.29$ and 0.28 respectively) and measures of squat jump, countermovement jump and the reactive strength index ($r = -0.46$, -0.42 and -0.41 respectively). While the significance of strength and power can be noted, the validity of the lunge test may be questioned. Arguably, measuring a full, self-selected lunge, rather than one that is determined by leg length dimensions would also account for flexibility and arm span, which have been identified as important factors in tennis based lunges (Cronin, McNair, & Marshall, 2003). This would also enable those that have a longer lunge consequent to enhanced force generation capabilities to be noted. Finally, the time taken for the chest to break through a beam may not represent the time taken for the sword to make contact with the target; it also neglects the significance of arm velocity, which is considered fundamental (Stewart & Kopetka, 2005). Guilhem *et al.,* (2014) used a 6.6 m-long force place system where elite female sabreurs (French national team; N = 10) performed a lunge preceded by a step, from which displacement and velocity was calculated and compared to dynamometry strength testing of the hip and knee. The fencers' centre of mass travelled 1.49 ± 0.19 m in 1.42 ± 0.08 s and at a peak velocity of 2.6 ± 0.2 m/s, generating a peak force of 496.6 ± 77.4 N. Maximal velocity was significantly correlated to the concentric peak torque produced by the rear hip ($r = 0.60$) and knee ($r = 0.79$) extensor muscles, as well as to the front knee extensors ($r = 0.81$). Again the significance of strength may be noted, but a void

still remains across more dynamic tests and with respect to anthropometrics. Also no target was used and thus time to hit still remains an unknown variable.

With respect to CODS, again only Tsolakis *et al.,* (2010) investigated this, via a "shuttle test". Here, photocells were placed at the start and end of a 5 m distance. As fast as possible, the fencer moved with correct fencing steps forward and back between them, covering a total distance of 30 m. Scores attained by elite and sub-elite fencers were 12.43 ± 0.95 s and 13.28 ± 0.93 s respectively and were significantly correlated to height, countermovement jump height and the reactive strength index following a drop jump from a 40 cm box (r = -.25, -.63, -.44 respectively). These relationships are suggestive of the positive effects of long limbs (presumably affecting "stride length") and lower-body power. Given that average work times for fencers of epee, foil and sabre are ~ 15 (much of which is sub-maximal), 5 (Roi & Bianchedi, 2008) and 2.5 s (Aquili & Tancredi, 2013) respectively, and changes in direction usually occur over shorter distance than 5 m, results may not best represent "on piste" CODS and thus additional more sport specific tests are required.

Therefore the aim of this study is to identify the physical characteristics that underpin both lunge and CODS performance, using tests that build on the aforementioned research. As such, the lunge will be determined using a force plate system that allows fencers to travel their "optimal" distance to strike a target. Reporting this with respect to time, i.e., lunge velocity, would normalize results for those that could lunge further but may take longer and vice versa. Also, a CODS test that replicates bout performance will be used, involving changes in direction required over shorter distances, coupled with a shorter overall distance and thus time to completion. Both test scores will be compared to anthropometric measures

and dynamic measures of lower body power. Given the significance of front leg strength and lower-limb muscle imbalance, these will also be measured. On the basis of these previous investigations, the following has been hypothesized:

Alternative hypothesis: Both front and rear leg power will correlate to lunge and CODS performance, as would stature, arm-span and flexibility. Furthermore, it is predicted that the high impact forces during the landing phase of a lunge, would generate a lower-limb strength imbalance favouring the front leg.

Null hypothesis: no measures of anthropometry and lower body power will be associated with lunge or CODS performance.

4.2 METHODS

4.2.1 Participants

Seventy male (*n* = 49) and female (*n* = 21) fencers from the British Fencing National Academy took part in this study. Fencers from each sword, i.e., epee (*n* = 30), foil (*n* = 21) and sabre (*n* = 19) were tested, and on average (± SD) were 16.83 ±1.72 years of age, 178.13 ± 8.91 cm tall, 68.20 ±9.64 kg in mass and had 6.25 ± 2.23 years fencing experience. The Middlesex University Ethics Committee approved the study and each participant (or parent/guardian where relevant) provided written informed consent before taking part in the research. All participants were familiar with the testing protocol as it was regularly completed throughout their season at training camps. Given the age range of the fencers, it was possible that some athletes may be late matures and thus undergoing a "growth spurt". Where this was

detected (using calculations described below), the fencer's data was not included in the final analysis.

4.2.2 Testing

Tests were selected to measure lower-body power and reactive strength. In addition to height and weight, anthropometric data included sitting height (and thus leg-length), arm span and flexibility. The inclusion of leg length also enabled the estimation of peak height velocity as described by Mirwald *et al.,* (2002); a measure used to control for variations in maturation, ensuring all fencers could be classed as adolescent and thus performance not affected by the neuromuscular and stature related alterations consequent to the growth spurt (Mirwald & Bailey, 2002). All tests were conducted on the same day, in the build up to a European competition, and all athletes were healthy and in good fitness.

Anthropometry (height and body mass), lower-body power (using Optijump) and CODS were measured as described in chapter three (general methods). Specific to this investigation, sitting height was measured with the only difference to standing height being that participants sat on a box, with their thighs parallel to the ground to ensure their spine was in a neutral position. This value provided an approximated peak height velocity using the regression equation devised by Mirwald *et al.,* (2002) as identified in equations one (for boys) and two (for girls). Furthermore, flexibility was measured as the linear distance between the lateral malleolus of each leg during a split in the frontal plane (Cronin, McNair, & Marshall, 2003) and arm span was measured as the linear distance between the middle finger tips, with the arms out to the side and parallel to the ground. All scores were recorded to the nearest 0.1 cm, using flexible tape.

Equation one.

*Maturity offset (boys) = -9.236 + (0.0002708*Leg length and sitting height interaction) – (0.001663*age and leg length interaction) + (0.007216*age and sitting height interaction) + (0.02292*weight by height ratio).*

Equation two.

*Maturity offset (girls) = -9.376 + (0.0001882*Leg Length and Sitting Height interaction) + (0.0022*Age and Leg Length interaction) + (0.005841*Age and Sitting Height interaction) – (0.002658*Age and Weight interaction) + (0.07693*Weight by Height ratio,).*

Lunge performance. Fencers were instructed to lunge and strike a target as fast as they could, but from what they deemed to be their optimal distance. Fencers were aware that there may be a compromise between distance and time and that to favour one may disadvantage the other. The target was a round pad with a diameter of 24 cm; the fencer could adjust the height of the target. The fencer was filmed in the sagittal plane using a Casio EX-ZR1000, recording at 480 fps. Data was then analysed using Kinovea software (http://www.kinovea.org/) to determine lunge distance (LD) and time. Lunge velocity was calculated as *distance/time*. The start of the lunge (and start of timing) was considered as the first forward movement of the front knee that was not immediately followed by a backward movement. This definition accounts for the fencer's tendency to "bounce" in preparation for attack and was found to be the most reliable point during pilot testing. Time was stopped once contact had been made with the target.

Fencers also lunged to and from a surface mounted force plate (type 92866AA, Kistler Instruments Ltd., Hook, United Kingdom), enabling the quantification of lunge forces at push-off and landing. Push-off peak force (POPF) was measured in the back leg and peak landing forces and rate of loading were measured in the front leg. POPF was reported relative to body mass and expressed as N/kg and peak landing forces (PLF) were expressed relative to body weight in line with previous studies (West, et al., 2011). During pilot testing it was found that impulse (using time to hit) and rate of force development (RFD) measured at 30, 100, 200, 300 ms and time to peak force were unreliable and therefore not used in subsequent analysis.

To improve the reliability of force-time data and better differentiate trials, athletes were asked to "freeze" in the start position prior to each lunge. To determine reliability, fencers performed 3 lunges, with the best scores used in the analysis. To calculate the ground reaction force derivatives described above, the resultant of the anterior-posterior and vertical forces was calculated and then filtered using a fourth-order zero-lag Butterworth low-pass filter with a 50 Hz cut-off for the back foot (push-off forces) and 44 Hz cut-off for the front foot (landing forces). Filter settings were determined by plotting the residual between the filtered and unfiltered signal as a function of cut-off frequency as described by Winter (2009).

4.2.3 Statistical Analysis

Measures of normality were assessed using the Kolmonogrov-Smirnov statistic. To determine the reliability of each assessment, single measures intraclass correlations (two-way random with absolute agreement) between trials were conducted. Pearson's product moment Correlation analysis was used to identify relationships between variables and a stepwise

multiple linear regression was used to identify the best predictors of lunge velocity and CODS. All statistical analysis was conducted using Statistical Package for Social Sciences (SPSS) version 21 with the level of significance set as $p < 0.05$. Due to the large sample size, it would be possible to identify significant correlations above 0.23, which, according to Cohen (1988), represents a "small" effect size. Therefore only significant correlations > 0.3, which are considered "moderate", were reported.

4.3 RESULTS

All data was normally distributed and intraclass correlations demonstrated a high level of reliability between trials of CMJ (r = 0.96), SLCMJ lead-leg (r = 0.92) and back-leg (r = 0.91), SBJ (r = 0.94), RSI (r = 0.86), lunge distance (r = 0.94), time (r = 0.87), velocity (r = 0.81), POPF (r = 0.90), PLF (r = 0.88) and CODS (r = 0.95). Results for all tests are illustrated in Table 4.1 and correlations are illustrated in Table 4.2. To avoid multicolinearity within the lunge regression model, CMJ was removed as it was highly correlated with SBJ (r = 0.87); SBJ had a higher correlation with lunge velocity and also enabled SLCMJ back leg to be included in the analysis (for CMJ and SLCMJ back-leg, r = 0.84). SLCMJ lead-leg was not included as it was highly correlated with SLCMJ back-leg (r = 0.87) and the latter was deemed to contribute to lunge velocity more. Therefore, only three variables (CMJ, SLCMJ back-leg and POPF) were entered (noting that no anthropometric data correlated with lunge velocity) into the regression model, which given the sample size (n = 70), was deemed acceptable (Field, 2013). The best predictor of lunge velocity was a one variable model using SBJ (Table 4.3). For the CODS regression model, height, flexibility, SBJ, SLCMJ back-leg and RSI were entered. Again, the best predictor of lunge velocity was a one variable model using SBJ (Table 4.4).

Table 4.1 Descriptive statistics for anthropometric and strength and power variables in British Fencing National Academy Fencers (n = 70)

Variable	Mean (SD)	Standard deviation
APHV	1.63	1.21
Leg-length (cm)	92.50	7.01
Arm-span (cm)	171.91	10.56
Flexibility (cm)	147.75	17.49
SBJ (cm)	177.7	0.32
CMJ (cm)	34.33	7.33
SLCMJB (cm)	17.1	4.64
SLCMJF (cm)	18.86	4.65
Asymmetry (%)	9.3	8
RSI	2.27	0.56
Peak push-off force (N/kg)	14.61	2.47
Peak landing forces (BW)	2.83	1.16
Lunge distance (cm)	148. 28	25.06
Lunge time (s)	0.40	0.08
Lunge velocity (m/s)	3.35	0.70
Change of direction speed (s)	5.45	0.65

APHV = approximated peak height velocity; SBJ = standing broad jump; CMJ = countermovement jump; SLCMJ = single leg-countermovement jump, both back (B) and front (F); RSI = reactive strength index; BW = body weight

Table 4.2 Correlations for anthropometric and strength and power tests with lunge distance, time and velocity.

	Lunge distance	Lunge time	Lunge velocity	CODS
Height	.45	-	-	-.37
Arm-span	.37	-	-	/
Flexibility	.38	-	-	-
CMJ	.44	-	.49	-.49
SBJ	.43	-	.51	-.65
SLCMJB	.43	-	.38	-.46
SLCMJF	.37	-	.45	-.45
RSI	.38	-	-	-.41
Peak push-off force	.32	-	.38	/
Peak landing forces	.38	-	/	/

All correlations significant at $p < 0.001$. CODS = change of direction speed; SBJ = standing broad jump; CMJ = countermovement jump; SLCMJ = single leg-countermovement jump, both back (B) and front (F); RSI = reactive strength index; / = not tested; - = no correlation.

Table 4.3 Multiple Regression model to predict lunge velocity

Model	B	SE B	β
Constant	1.766	0.350	
SBJ	0.923	0.198	0.507*

Note. $R^2 = .257$. *$p < .001$

Table 4.4 Multiple Regression model to predict change of direction speed

Model	B	SE B	β
Constant	7.660	0.320	
SBJ	-1.279	0.180	-0.652*

Note. $R^2 = .425$. *$p < .001$

4.4 DISCUSSION

The data supports the alternative hypothesis, the exception being no association between anthropometry (i.e., measures of height, arm-span and flexibility) during LV. With regards to LV, most measures of lower-body power were associated, but SBJ had the highest correlation ($r = 0.51$) and was also the only variable to be used in the multiple regression model, which accounted for 26% of the variability in the score. Height and flexibility did however, correlate with lunge distance (see Table 4.3). Based on previous research, flexibility was expected to show some relationship (Cronin, McNair, & Marshall, 2003), as enhanced mobility within the adductor complex would likely allow fencers to lunge further. Longer legs (again allowing a greater stride), coupled with a longer torso (and thus a greater lean towards the target) would also enable fencers to do the same.

The CODS test was completed in 5.45 ± 0.65 s and thus better replicates the approximated work duration of a fencing point. While epee and foil have longer "work" times, much of this is at a sub-maximal intensity; also sabre's work duration is averaged at half of this but it is expected that using a CODS that would take less than 3 s would negatively affect test reliability. The CODS was correlated with all variables (except flexibility where stride length

was presumably not great enough to affect this) and similar to LV, SBJ had the highest correlation (r = -0.65). It was also the only variable to be used in the regression model, accounting for 43% of the variability in the score. Like LV, CODS is correlated to lower-body power, but also leg-length, which may in part dictate stride length. RSI is correlated, which given the need for "fast feet" and thus reduced ground contact times, is not a surprising finding. This is the first study to identify scores for CODS over sprint-based distances in fencing, so a comparison with other studies is not possible.

The lack of any correlation with lunge time across all variables may suggest that the ability to generate lower-body power, cancels out the assumed greater time expected for taller fencers (who travel a larger distance) to hit the target. That is, enhanced lower-body power also enables fencers to take up their en guard position further away from their opponent. It may also suggest that fencers tend to opt for standing a greater distance from the target (and staying out of range), rather than reducing time to contact. In essence, fencers used their perceived propulsive forces to move further away from the target (beyond that dictated by their anthropometrics), rather than maintain distance and hit the target in a shorter time. This inference is supported by the consistent significant correlations between measures of lower-body power and lunge distance. Equally, it is measures of lower-body power, rather than anthropometric characteristics, which better relate to LV. Anecdotally, coaches also generally teach their athletes to maintain an "out of range" distance from their opponent. Results may suggest that the "optimal", self-selected lunge, is a technique not only standardized by anthropometric measures, but also the ability to generate force and propel ones self forward. Of course, the results here are specific to adolescent (~ 17 years) fencers as their age may see a varying transition through puberty and thus differing peak height velocities with concomitant leg-length to torso ratios (Mirwald & Bailey, 2002). However, all efforts were

made to ensure fencers were post pubescent and the effects of this minimized. This may be evidenced by the APHV scores, which were above one (Table 4.1).

A higher correlation between POPF (N/kg) and LV was expected, especially given the correlations with lower-body power including single-leg jumps. Also, Guilhem *et al.,* (2014) through electromyography (EMG) analysis, showed that the activation of rear leg extensor muscles i.e., gluteus maximus, vastis lateralis and soleus, was correlated to LV (r = 0.70, 0.59 and 0.44, respectively). On re-examination of the video footage, it is clear that some fencers initiate the lunge with extension of the legs, while others (correctly for the purpose of "priority" scoring) with extension of the lead arm; a discrepancy in technique noted elsewhere (Gholipour, Tabrizi, & Farahmand, 2008; Gutierrez-Davila, 2011). If the latter is performed incorrectly, it may have the effect of shifting the athlete's centre of mass forward and thus reducing the ability of the athlete to generate force at the back leg due to its reduced active state, see Bobbert and Casius (2005) for further details. If coupled with torso lean, this could also result in changes to the length-tension relationship across various muscle groups, including the hip extensor complex. If such assertions were true, they would warn of the negative consequences of a lead arm that does not move independent of the body; fencers should not feel that this movement shifts their weight forward favouring the front leg, or causes the torso to lean towards the target.

The average lunge distance was 148.28 ± 25.06 cm. This was further than that noted by Gholipour *et al.,* (2008), but similar to Gutierrez-Davila *et al.,* (2011) (117 and 140 cm respectively). Compared to Guilhem *et al.,* (2014), and acknowledging their lunge was preceded by a (small) step but our fencers were taller (~8 cm), distance travelled appears similar. The average lunge time (from initiation to sword contact with target) was 400 ± 8 ms.

This was quicker than Gholipour *et al.,* (2008), Gutierrez-Davila *et al.,* (2011) and Guilhem *et al.,* (2014) (1082, 601 and 1430 ms respectively). In the study of Gholipour *et al.,* (2008), fencers were asked to lunge with no target to aim at, with time stopped at completion of the lunge, which may follow the swords contact with the target as this can occur with the front foot still airborne. Also, data was recorded at 50 Hz, creating a probable error of ± 20 ms. In the study of Gutierrez-Davila *et al.,* (2011) lunge distance was set at 1.5-fold the height of the fencer. While time was stopped when the sword made contact with the target, fencers first had to respond to a visual cue, thus including a reactive element. In the Guilhem *et al.,* (2014) study, the lunge was preceded by a step as well as measured until the front foot made contact with the floor, rather than the sword with the target. Only Tsolakis and Vagenas (2010) have found quicker lunge times. They reported scores of 180 ± 30 ms and 210 ± 40 ms in elite and sub-elite Greek Fencers respectively. As aforementioned, they used a different protocol (four photocells placed at a lunge distance of 2/3-leg length, with the height of the photocells adjusted to be interrupted by the chest) making comparisons difficult.

Like Tsolakis and Vagenas (2010) and Tsolakis *et al.,* (2010) correlations were found between lead leg power and lunge performance, which given the landing forces experienced (~ 3 times body weight) and thus the need to demonstrate and develop high eccentric (braking) strength (Guilhem, Giroux, Chollet, & Rabita, 2014), is not a surprising outcome. Also, given its correlation with LD, it appears that this will continually develop with increases in stature and the ability for rear leg propulsion. The association is of course indirect, as the measurement of lower-limb muscle activation has revealed the lunge is performed via rear leg propulsion (Guilhem, Giroux, Chollet, & Rabita, 2014). The high landing forces also explain the asymmetries noted here and previously (Guilhem, Giroux, Chollet, & Rabita, 2014) and although these fencers are ~ 17 years, they are already close to

the threshold (> 15%) for which the likelihood for injury is high (Impellizzeri, Rampinni, & Marcora, 2007) and performance may be compromised (on average, fencers had asymmetry of 9.3%). Although not measured here, it is likely that the force required to return to the en-guard position following the competition of the lunge, will add to this asymmetrical issue.

The results herein add to the growing evidence that strength and power characteristics positively correlate to lunge and CODS performance. We would also add stature and flexibility in the adductors as having beneficial effects. We also highlight the concerns of others regarding lower-limb asymmetries in favour of the front leg on account of high landing forces (and probably the need to recover from this position). This will increase the risk of injury and compromise performance and is an issue already apparent in many of these adolescent fencers. Unfortunately, time based derivatives of force (i.e., RFD and impulse) where too unreliable to be used for analysis. Future investigations should look to standardize the lunge position better, requiring static poses in the start position in excess of 3 s to reduce active state (Bobbert & Casius, 2005). That said, reliability issues with measuring RFD, given the short time frames (e.g., 30 – 100 ms) and the effect of movement prior to the start of a test, have been noted elsewhere (West, et al., 2011).

4.5 CONCLUSIONS AND PRACTICAL APPLICATIONS

Training the lunge. Based on these results, fencers of smaller stature (and thus reduced attacking range) can compensate for this by working on the ability to generate force, especially in the horizontal direction. Training programmes should look to include horizontal jumping, bi-lateral and unilateral. Of note, the SLCMJ lead-leg was also correlated with distance and velocity and, despite not being as responsible for propelling the body forward

while lunging, had higher jump scores than the back-leg (18.86 ± 4.65 cm *vs.* 17.1 ± 4.62 cm). It may be that this is an outcome of the high landing forces generated from the lunge, as well as the push-off force then required to quickly recover back to the en guard position; both are likely to translate to strength gains. These may reveal the benefits of exposing the back-leg to higher landing/eccentric forces as part of training, as well as high concentric forces from a relatively deep squat position (thighs at least parallel to the floor). Finally, despite the relatively young age of the fencers (16.83 years), the 6.25 years experience in fencing has already generated a lower-limb asymmetry between the front leg and back leg of 9.3%. Given that a 15% difference is a probable indication of impeding injury (Impellizzeri, Rampinni, & Marcora, 2007), this needs to be addressed. As well as more single-leg work on the weaker leg (generally the back leg), switching the stance during warm-ups may be one way of addressing this.

Training CODS. Exercises that develop lower-body power, especially with horizontal propulsion, may be beneficial. These should also be supplemented with exercises that develop reactive strength such as drop jumps and hurdle jumps; perhaps the latter will have a greater carry-over given its horizontal displacement, as SBJ (horizontal displacement) showed a stronger correlation than CMJ (vertical displacement). Finally, taller athletes tend to be at an advantage; perhaps due to an ability to maximize stride length.

Chapter 5

STUDY TWO. PHYSICAL CHARACTERISTICS UNDERPINNING REPETITIVE LUNGING

5.1 INTRODUCTION

Fencing involves a series of explosive attacks, spaced by low-intensity movements with varying recovery periods, predominately taxing anaerobic metabolism (Wylde, Frankie, & O'Donoghue, 2013; Guilhem, Giroux, Chollet, & Rabita, 2014). The lunge is the most common form of attack (Aquili & Tancredi, 2013), usually delivered after several changes in direction (and feints) (Roi & Bianchedi, 2008), used to evade and disguise the hit. For example, during each bout, a fencer may cover between 250-1000 m, attack 140 times and change direction nearly 400 times in women's epee and around 170 times in men's epee and foil (Roi & Bianchedi, 2008). In sabre, there are on average 21 lunges, 7 changes in direction and 14 attacks per bout (Aquili & Tancredi, 2013). The work to rest ratios vary between swords, but it is clear that as the competition progresses and fencers reach the elimination bouts, the intensity and anaerobic nature of fights increase, with lactate values rising from around 4 mmol/L in the preliminary bouts, to being consistently above this (and as high as 15.3 mmol/L) during the elimination bouts (Cerizza & Roi, 1994). Given the repetitive demand to effectively execute lunging and CODS within each bout, the ability to sustain these at maximal capacity is likely to be fundamental to performance. As yet this quality has not been reported on in the literature, and subsequently nor have the physical characteristics that underpin this feat of speed and power endurance. The aim of this study therefore, is to report scores on this variable, referred to as repeat lunge ability (RLA), as well as identifying

the physical characteristics that underpin its successful execution. Noting that associations from this could only be considered theoretical, the second aim of this study was to identify if improvements in RLA could indeed be made if these exercises were trained and subsequently improved. Because the RLA test involved lunging and change of direction speed, it was hypothesised that similar associations to those identified in study one would be noted. Furthermore, given the demands of the test, which was designed to surpass the intensity of a fencing bout, it was also expected that an athlete's buffering capacity would affect this score. In summary, the following has been is hypothesised:

Alternative hypothesis: RLA will be associated with measures of lower leg power and CODS; this association will be confirmed through a training group study.

Null hypothesis: RLA will not be associated with measures of lower leg power and CODS.

5.2 METHODS

5.2.1 Participants

The first part of this investigation, i.e., the determination of physical characteristics that underpin RLA, involved thirty-six fencers from the British Fencing World Class Performance (WCP) and World Class Potential squad, averaging (± SD) 18.9 ± 3.2 years of age, 174.35 ± 10.42 cm tall, 70.67 ± 7.35 kg in mass, and 8.5 ± 4.2 years fencing experience. The training of any identified physical characteristics and subsequent re-testing of RLA (to evaluate any associations found) used a sample of these. Several senior fencers (n = 7) comprised the training group (TG) as they were full-time athletes receiving supervised strength and conditioning training (subject characteristics as follows: 20.6 ± 2.4 years of age, 177.71 ±

4.37 cm tall, 74.41 ± 6.93 kg in mass, and had 10.0 ± 3.8 years fencing experience). The junior fencers (n = 8) were the control group (CG) and those that remained within the programme thus able to report for subsequent re-testing; this group received no supervised strength and conditioning training (subject characteristics as follows: 17.7 ± 1.4 years of age, 178.43 ± 9.25 cm tall, 72.71 ± 6.63 kg in mass, and had 8.1 ± 3.6). All fencers were familiar with the testing protocol as it was regularly completed throughout their season, and all were healthy and in good fitness. The Middlesex University Ethics Committee approved the study and each fencer provided written informed consent before taking part in the research. All fencers were familiar with the testing protocol as it was regularly completed throughout their season, and all were healthy and in good fitness.

5.2.2 Testing

Tests were selected to measure lower-body power and reactive strength, speed (forward and backward), CODS and RLA. Speed, CODS and RLA testing was conducted on a metal competition piste to increase validity of results, and all tests were conducted on the same day.

Anthropometry (height and body mass), lower-body power (using Optijump) and change of CODS were measured as described in chapter three (general methods). Specific to this investigation, was the assessment of speed and RLA, and the inclusion of strength and conditioning training for the intervention group, which are described below.

Speed. Using fencing footwork, fencers had to travel between two sets of timing gates (positioned at hip height) spaced 7 m apart. Fencers' speed was tested going forward

(SPDFwd) as well as going backwards (SPDBk). The test was immediately stopped if the athlete used footwork deemed by the fencing coach to be unrepresentative of proper form, or if the beam was broken at the start or finish line with any part of their body other than their hips.

Repeat Lunge Ability (RLA). Using fencing footwork, fencers they travelled 7 m towards a mannequin where they performed a lunge to hit either its chest or head guard. They then changed direction, traveling backwards until their lead toe was behind a 4 m line. From here they continued to hit the mannequin a further 4 times, traveling back to the 4 m line between hits; only following the last hit (5^{th}) did they then travel back past the start line (positioned 7 m from the mannequin). This was repeated 5 times with 10 s rest between intervals, with the score recorded as the average time across the 5 intervals. Timing gates were positioned at hip height at the start line, which fencers broke to both start and conclude each interval. Due to the unreliable data noted when fencers continually break the beam of light gates within a test (see CODS methodology, chapter three), the start line was set a further 3 m back from the mannequin relative to the within-interval shuttle line (4 m line). The test was void if the fencer used footwork or a lunge technique deemed by the fencing coach to be unrepresentative of proper form, or if the fencer failed to pass either line with their toes.

This test was derived from pilot testing, considered valid on account of fencers having to cover an 8 m distance (4 m to and 4 m back from target) between hits, which is a short enough distance to be specific to the sport, but long enough to ensure several steps prior to each lunge. Because elimination bouts (of all swords) induce high levels of blood lactate, the test must also include (several) work intervals long enough to stimulate the onset of blood lactate accumulation (OBLA), and thus challenge the fencers to work in the presence of high

concentrations of hydrogen ions. Without the psychological arousal associated with competitions, this therefore required deviating from the established work to rest ratios of the sport, with the recovery from each lunge and the continuous changing of direction considered to largely contribute to fatigue (See chapter two). Pilot testing revealed blood lactate values of 6.7 ± 1.8 mmol/L.

5.2.3 Strength and Conditioning Training

All WCP athletes performed two strength and power sessions and two conditioning session a week for 16-weeks before being re-tested. Strength and power training consisted of various squats and weightlifting exercises and derivatives, coupled with plyometrics such as jump to box, drop jumps and hurdle jumps. These exercises are well supported in their ability to increase jump and CODS performance (Asci & Acikada, 2007; Peterson, Alvar, & Rhea, 2006). Conditioning sessions consisted of high intensity interval training, designed to induce high levels of blood lactate (Baker, 2011). Work to rest ratios of 1:1 were used, usually 30 or 15s in length, consisting of cross training activities such as bike and rowing ergometer sprints, sled pulls and battle ropes (Baker, 2011). Conditioning sessions consisted of one or two reps of 3-5 min, over 1-3 sets, 1 min between sets. Strength and conditioning sessions are detailed in section 3.8 of the general methods sections.

5.2.4 Statistical Analysis

Measures of normality were assessed using the Shapiro-Wilk statistic. To determine the reliability of all tests of lower-body power, three trials were conducted and single measures ICC (two-way random with absolute agreement) between trials were conducted; the highest score of each trial was used for subsequent analysis. Pearsons Product Moment correlation

analysis was used to identify relationships between variables and a stepwise multiple linear regression was used to identify the best predictors of RLA. Differences in pre and post RLA, SBJ and CODS scores for TG and CG fencers was investigated using a paired-samples *t*-test, with differences also reported as effect sizes (Hopkins, 2004) and interpreted according to Rhea (2004), with athletes classed as "highly trained". Differences between the TG and GC were also explored by way of independent samples *t*-tests. All statistical analysis was conducted using SPSS version 21 with the level of significance set at $p < 0.05$.

5.3 RESULTS

All data was normally distributed and intraclass correlations demonstrated a high level of reliability between trials of all variables (Table 5.1). Results for all tests are illustrated in Table 5.1 and correlations are illustrated in Table 5.2. Due to sample size, only four variables were entered into the regression model: RSI, CODS, SPDBk (as it had a higher correlation with RLA than SPDFwd) and SBJ (on account of it having the highest correlation with RLA of all lower-body power tests). Results reveal that all variables are strongly correlated with RLA, but in particular CODS and SBJ. Indeed, linear regression analysis revealed that these two variables best predict RLA scores, collectively accounting for 61% of the common variance in the score (Table 5.3).

Table 5.1 Test results presented as means (±SD) with associated reliability scores using single measures intraclass correlations (ICC) and 95% confidence intervals (95%CI).

Test	Mean	SD	ICC	95%CI
Countermovement Jump (cm)	40.13	7.76	0.96	0.94 - 0.98
Single-leg jump Front foot (cm)	23.01	4.79	0.96	0.93 - 0.98
Single-leg jump back foot (cm)	20.57	4.78	0.93	0.84 - 0.96
Reactive strength index	1.65	0.44	0.92	0.85 - 0.96
Standing broad jump (cm)	204.17	26.22	0.96	0.90 - 0.98
Agility (s)	4.65	0.41	0.98	0.97 - 0.99
Speed forward (s)	1.98	0.24	0.98	0.96 - 0.99
Speed backward (s)	2.10	0.24	0.98	0.97 - 0.99
Repeat lunge ability (s)	16.38	1.40		

Table 5.2 Correlations been tested variables associated with RLA

	CMJ	SLJFr	SLJBk	RSI	SBJ	Agility	SPDFwd	SPDBk
SLJFr	.83**							
SLJBk	.77**	.89**						
RSI	.75**	.79**	.70**					
SBJ	.79**	.70**	.64**	.61**				
Agility	-.57**	-.54**	-.53**	-.56**	-.58**			
SPDFwd	-.53**	-.57**	-.57**	-.45**	-.39*	.62**		
SPDBk	-.54**	-.55**	-.51**	-.59**	-.44**	.76**	.79**	
RLA	-.60**	-.58**	-.57**	-.53**	-.68**	.70**	.40*	.48**

Key: CMJ = countermovement jump; SLJFr = single leg jump front foot; SLJBk = single leg jump back foot; RSI = reactive strength index; SBJ = standing broad jump; SPDFwd = speed forward; SPDBk = speed back; RLA = repeat lunge ability; * Correlation is significant at the 0.05 level; ** Correlation is significant at the 0.01 level

Table 5.3 Multiple regression models to predict repeat lunge ability

	B	**SE *B***	**β**
Step 1			
Constant	4.91	2.03	
Agility	2.47	0.44	0.70*
Step 2			
Constant	13.55	3.35	
Agility	1.63	0.48	0.46*
Standing broad jump	-0.02	0.01	-0.42*

Note: R^2 = .49 for step 1, Δ R^2 = .61 for step 2 (p < .001). * p < 0.001.

Following strength and conditioning programming to improve agility and SBJ scores in WCP athletes, RLA significantly (p < 0.05) improved from 15.80 ±1.07 s to 14.90 ±0.86 s, with the magnitude of change reported as "moderate" (ES = 0.93). Similarly, improvements were noted in both SBJ (216.86 cm ± 17.15 *vs.* 221.71 ± 17.59 cm) and agility (4.44 ± 0.29 s *vs.* 4.31 ± 0.09 s) and while differences were only significant in SBJ, magnitudes of change were classed as "small" (ES = 0.28) and "moderate" (ES = 0.61) respectively. In contrast, the CG fencers made non-significant (p > 0.05) improvements in RLA (16.02 ± 1.14 s to 15.84 ± 1.13), with the magnitude of change reported as "trivial" (ES = 0.17). Improvements (albeit non-significant) were also noted in both SBJ (205.91 cm ± 13.09 *vs.* 208.64 ± 10.62 cm) and CODS (4.64 ± 0.29 s *vs.* 4.62 ± 0.27 s), with magnitudes of change classed as "trivial" in both (ES = 0.23 and 0.08 respectively).

5.4 DISCUSSION

The RLA test had average work times of 16.30s (± 1.40) and was correlated to all other tested variables, but in particular CODS (r = 0.70) and SBJ (r = -0.68). Through linear regression analyses, these variables provided a two-predictor model accounting for 61% of the common variance associated with RLA; therefore data supports the alternative hypothesis. Based on these findings, a fencer's ability to repetitively lunge and change direction, with maximal intensity throughout each bout, can be facilitated by increasing CODS, linear speed (forward and backward) and lower-body power including RSI. Furthermore, when investigating the trainability of RLA and specifically, if increases in CODS and SBJ improved its performance (in accordance with the regression analysis), significant improvements were noted (from 15.80 ±1.07 s to 14.90 ±0.86 s). This mirrored improvements in CODS and SBJ, however, only in the latter were improvements significant, but nevertheless, changes in CODS scores were considered "moderate" using effect size analysis. Analysis within the control group also revealed improvements in these variables, however, these changes were non-significant and classed as "trivial". It therefore appears reasonable to suggest that larger improvements in SBJ and/or agility would also result in larger improvements in RLA. The concept of increasing fencing specific movements such as lunging and CODS through strength and power training have also been advocated elsewhere (Guilhem, Giroux, Chollet, & Rabita, 2014; Redondo, Alonso, Sedano, & de Benito, 2014). It is also interesting to note that SPDBk is better correlated to RLA (and CODS) than SPDFwd (r = .48 and .40 respectively), and may highlight the need to further expose athletes to this type of training within fencing coaching sessions.

The correlations herein, between a sport specific speed endurance test and various anaerobic power tests, have been reported in numerous other investigations of repeat sprint ability (Da Silva, Guglielmo, & Bishop, 2010; Pyne, Montgomery, Hewitt, & Sheehan, 2008; Sant'Ana Pereira, Sargeant, Rademaker, de Haan, & Van Mechelen, 1996), and the associations here may act to further support fencing as an anaerobic power-based sport (Wylde, Frankie, & O'Donoghue, 2013; Guilhem, Giroux, Chollet, & Rabita, 2014). That said, no measures of aerobic capacity were taken to further qualify this statement, but given that the sample contained elite athletes in the middle of the competitive season, this was not possible. Also, only 61% of the common variance in RLA scores was predicted using the two-predictor model (Table 3), leaving 39% unaccounted for. It may be that this would be further explained by a fencer's aerobic capacity, or, in the opinions of the authors (and given the RLA protocol), their lactate deflection points. That is, conditioning designed to enable fencers to work at higher intensities before reaching the onset of blood lactate accumulation, as well as working in the presence of hydrogen ion accumulation, would achieve greater scores still. Therefore it is likely that the conditioning work undertaken by these athletes, and the physiological improvements made consequent to this, may also be responsible for the noted improvement in RLA scores of the WCP fencers; future research should attempt to validate this statement.

Finally, and of note, the footwork incorporated within the CODS and speed drills that inevitably dictate a large part of the score, is beyond the remit of the strength and conditioning coach, and is thus better affected indirectly. Noting that measures of lower-body power are correlated to these, one such method may be by virtue of increasing this physical attribute. Similar relationships have been reported by Tsolakis *et al.,* (2010) who found a relationship between CMJ and RSI, and scores derived from a shuttle test, where fencers

moved as fast as possible between 5 m cones, covering a total distance of 30 m (average score 12.43 s). Here they reported correlations of r = -0.63 and -0.44 for CMJ and RSI respectively.

5.5 CONCLUSIONS AND PRACTICAL APPLICATIONS

Strength and power training has already been found to improve lunging and CODS in fencers. It is now also advocated to improve RLA and thus the ability to sustain attacking actions within a fencing bout. Strength and conditioning coaches should focus on improving lower-body power and reactive strength, noting that jump training and plyometrics designed to enhance horizontal propulsion may be most effective and translate to improvement in CODS also. Furthermore, given the high levels of lactate expected to be generated in fencers as they progress in the competition, and the assumed validity of the RLA test, conditioning training designed to enable fencers to work at higher intensities before reaching OBLA, as well as working in the presence of hydrogen ion accumulation, would further improve performance through enhanced speed and power endurance.

Chapter 6

COMPETITION INTENSITY AND FATIGUE IN OLYMPIC FENCING

6.1 INTRODUCTION

The Olympic sport of Fencing has been investigated numerous times to describe the kinetics, kinematics and physical requisites of the attacking lunge (Guilhem, Giroux, Chollet, & Rabita, 2014; Gholipour, Tabrizi, & Farahmand, 2008; Gutierrez-Davila, 2011; Tsolakis, Kostaki, & Vagenas, 2010; Stewart & Kopetka, 2005) and more recently as part of this thesis, CODS (study one, chapter three) and speed endurance (study two, chapter four). As yet, no studies have looked to physiologically describe the effect of competition intensity and residual fatigue on biochemical and physiological changes in order to inform training programme design. For example, measures of heart rate (HR), blood lactate (BL) and ratings of perceived exertion (RPE) taken within competition, can determine metabolic workload and the demands placed on the respective energy systems (Coutts, Rampinini, Marcora, Castagna, & Impellizzeri, 2009; Haddad, Chaouachi, Castagna, Wong, Behm, & Chamari, 2011; Uchida, et al., 2014; Wallace, Slattery, & Coutts, 2009). Saliva analysis can reveal the (physical and emotional) stress of competition (and requirements for rest and recovery) by describing hormonal fluctuations in testosterone (T) and cortisol (C) (Cormack, Newton, McGuigan, & Cormie, 2008; McGuigan & Cormack, 2011; Mclellan & Lovell, 2010), activation of the sympathetic nervous system through concentration changes in salivary alpha amylase (sAA) (Chatterton, Vogelsong, Lu, Ellman, & Hudgens, 1996; Calvo, et al., 1997; Chiodo, Tessitore, & Cortis, 2011) and any signs of immune-depression through reductions in immunoglobulin A (IgA) (Neville, Gleeson, & Folland, 2008; Libicz, Mercier, Bigou, Le Gallais, & Castex, 2006; Novas, Rowbottom, & Jenkins, 2003; Gleeson, McDonald, & Pyne,

1999). For example, McLellan *et al.,* (2010) monitored the T : C response following a rugby league match and reported significant reductions which did not return to baseline values until 48-hrs post match. This time point was suggested to be indicative of when training could safely resume without an increased risk of overtraining, injury or illness. Kivlighan and Granger (2006) showed that 2-km ergometer rowing increased sAA levels, and the magnitude of which was positively associated with performance. This trend has also been noted in marathon running (Ljungberg, Ericson, Ekblom, & Birkhed, 1997), triathlon (Steerenberg, van Asperen, Van Nieuw Amerongen, Biewenga, Mol, & Medema, 1997), 60-min cycle races (Walsh, Blannin, Clark, Cook, Robson, & Gleeson, 1999) and a taekwondo competition (Chiodo, Tessitore, & Cortis, 2011). Finally, the incidence of upper respiratory tract infections (URTI) is associated with increases in training load and a reduction in salivary IgA levels (Neville, Gleeson, & Folland, 2008; Libicz, Mercier, Bigou, Le Gallais, & Castex, 2006; Novas, Rowbottom, & Jenkins, 2003; Gleeson, McDonald, & Pyne, 1999), an association supported by longitudinal studies examining triathletes (Libicz, Mercier, Bigou, Le Gallais, & Castex, 2006), swimmers (Gleeson, McDonald, & Pyne, 1999; Gleeson, McDonald, & Pyne, 2000) kayakers (Mackinnon, Ginn, & Seymour, 1993) distance runners (Mackinnon & Hooper, 1994), football players (Fahlman & Engels, 2005) and rowers (Neville, Gleeson, & Folland, 2008). Specifically, Neville *et al.,* (2008) reported that when salivary IgA concentration dropped below 40% of an athletes mean healthy levels, they had a one in two chance of contracting an URTI within 3 weeks.

Measures of stretch shortening cycle capability are considered indicative of neuromuscular fatigue (Markovic, Dizadar, Jukic, & Cardinale, 2004; Mooney, Cormack, O'Brien, Morgan, & McGuigan, 2013; Johnston, Gabbett, Jenkins, & Julin, 2014; Johnson, Gibson, Twist, Gabbett, MacNay, & MacFarlane, 2013), with research showing that fatigue accumulation,

normally lasting 48-72 hours post exercise or competition, is detetected through a continued deficit in jump performance (Cormack, Newton, & McGuigan, 2008; Mooney, Cormack, O'Brien, Morgan, & McGuigan, 2013; Johnson, Gibson, Twist, Gabbett, MacNay, & MacFarlane, 2013; Coutts & Duffield, 2010). For example, McLellan *et al.,* (2010) found that following a competitive rugby league match, force-time data from a countermovement jump showed that peak rate of force development, peak power and peak force all dropped immediately after the match and lasted for 48-hrs. These findings mimicked the bodies stress response as measured by salivary C concentrations, and as such, salivary analysis coupled with measures of neuromuscular fatigue, may provide the temporal requirements to dissipate fatigue and return to full training without risking injury (Gabbett, 2004), illness (Neville, Gleeson, & Folland, 2008) and reductions in both competition and training performance (Elloumi, Makni,, Moalla, Bouaziz, Tabka, & Chamari, 2012).

Collectively therefore, all measures are proposed to combine to describe competition demand and the requirements for recovery, affecting exercise selection and the programming and periodisation of these. The aim of this study therefore, is to use all aforementioned measures to describe these demands within the Olympic sport of fencing in order to inform training programme design. Based on previous research, the following was hypothesised:

Alternative hypothesis: Fencing bouts, while being high-intensity, would not induce high levels of BL, and fencers would demonstrate progressive fatigue throughout the competition, not recoverng for 72 hours. Due to competition arousal, jump scores and values for T, C and AA immediately pre competition, would be higher than that measured at baseline.

Null hypothesis: Fencers would not experience fatigue during competition and bouts would significantly tax glycolytic metabolism as noted by high values of BL.

6.2 METHODS

6.2.1 Participants

Nine male fencers from the Great Britain Fencing Squad (foil) took part in the study. On average (mean ± SD), fencers were 22.33 ± 2.82 years of age, 179.23 ±5.51 cm tall, 74.20 ± 6.35 kg in mass, and had 14.25 ± 3.63 years fencing experience, with two having competed in the London 2012 Olympic games. Data was collected across two competitions spaced one week apart; one was an international competition and the other a national competition. Before the start of the study, all fencers attended a presentation outlining the purpose, benefits and procedures of the study and were familiarised with the saliva collection process. The latter was important, as some athletes would collect samples while at home; this has been shown to be a reliable method (Papacosta & Nassis, 2011). The Middlesex University Ethics Committee approved the study and each fencer provided written informed consent before taking part in the research. All fencers were of good fitness and healthy, i.e., free from illness; the latter was verified via questionnaire, which also looked to establish the health of any cohabitant (data not shown).

6.2.2 Procedures

Saliva samples and jump scores were collected across both competitions at the following time-points: 48, 24 hours and 30 minutes pre competition, and 30 minutes, 24, 48 and 72 hours post competition. All data was collected between 0900 and 0930 except for with-in and 30-minute post competition scores, which were variable and depended on the success of the fencer within the competition. To avoid the acutely high scores consequent to the cortisol awakening response (Clow, Thorn, Evans, & Hucklebridge, 2004), fencers were awake at least one hour prior to collection. Finally, on each competition day, fencers wore HR

monitors throughout, and BL and RPE were taken following each bout. Fencers rested 24 hours post competitions, engaged in recovery sessions 48 hours post competitions, and given the proximity of them, performed only light to moderate training sessions at all other time points, consisting of technical blade work, 5-point match sparring and reduced volume resistance training. Scores for each athlete were averaged across the competitions to better enable the generalisation of data, although differences between competitions were analysed and if found to be significant, expanded on. Jump scores were represented as changes from baseline, i.e., each score was divided by the values recorded at 48 and 24hours pre-competition respectively, thus accounting for individual variation (Papacosta & Nassis, 2011) – all raw scores however, are presented in Appendix E.

6.2.3 Salivary Sampling and Analysis

Unstimulated saliva was collected via passive drool into a cryovial for analysis of C, T, IgA, and sAA (Bishop & Gleeson, 2009; Proctor & Carpenter, 2007). In order to preserve the integrity of samples, fencers were instructed to avoid food, fluid (except water) and brushing their teeth, one hour before collection; 10 minutes prior to collection, fencers had to rinse out their mouth with water (Groschl, Kohler, Topf, & Rauh, 2008). After collection, samples were immediately frozen at -20°C (commercial freezer, where they remained for one week), before being transported to and stored at -80°C until analysis (Granger, Shirtcliff, Booth, Kivlighan, & Schwartz, 2004).

All salivary analytes were analysed in duplicate via a commercially available enzyme-linked immunosorbent assay (Salimetrics LLC, State College, PA, USA) using a microplate reader (Fluostar Omega, BMG Labtech, Aylesbury UK). Standard curves were constructed as per the manufacturer's instructions, and commercially available standards and quality control

samples were used for the assays (Salimetrics LLC). All samples were analysed in the same series to avoid inter-assay variability. The sensitivity and average intraassay CV was 0.007 µg/dL and 2.6% for C, 1.0 pg/mL and 2.5% for T, 2 U/mL and 6.7 % for sAA and 2.5 µg/dL and 5.32% for IgA. Full details of the analysis are presented in the general methods section (chapter three) and appendix D.

For SIgA and sAA, secretion rates were calculated. Firstly saliva flow rate had to be determined by dividing the sample volume (ml) by the time (min) taken to produce it (Mackinnon & Hooper, 1994); it was assumed that saliva density was 1.00g/ml (Walsh, Blannin, & A, 1999). SIgA and sAA secretion rate was then calculated by multiplying the absolute concentrations of each by the saliva flow rate (Mackinnon & Hooper, 1994). Unlike the other tested biomarkers, SIgA has been provided with a reference point to which sport scientist can take guidance (Neville, Gleeson, & Folland, 2008). Because of this, a drop below 40% of baseline values (48 hours pre competition) was also checked for each athlete.

6.2.4 Neuromuscular Fatigue, Heart Rate, Blood Lactate and Rating of Perceived Exertion

Neuromuscular fatigue was measured via a countermovement jump (CMJ) performed on a surface mounted force plate (type 92866AA, Kistler Instruments Ltd., Hook, United Kingdom); jump height, peak power and peak rate of force development were calculated as described in the general methods section (chapter 3). Fencers wore HR monitors throughout the competition, were average HR, maximum HR and time spent above 80% HRmax was calculated. BL and RPE scores were taken 5 min after each bout; the former was also taken prior to the start of the competition and all scores were averaged across both competitions, and separated to define pool bouts (first to 5 hits) and elimination bouts (first to 15 hits). However, scores were also analysed to determine if increases were noted following each

bout, as the competition progressed. The collection procedure for these is also described in the general methods section.

6.2.5 Statistical Analysis

Measures of normality were assessed using the Shapiro-Wilk statistic. To determine the reliability of each assessment, single measures intraclass correlations (two-way random with absolute agreement) between trials were conducted. Repeated measures ANOVA with bonferroni correction were performed to investigate temporal changes in CMJ and hormonal values; this test is also considered valid for non-parametric data (Field, 2013). During pilot testing large between subject variations were noted in salivary analyte concentrations and thus is was anticipated that these would ultimately invalidate significance testing. Therefore effect size analysis was also used sizes (Hopkins, 2004) and interpreted according to Rhea (2004), with athletes classed as "highly trained". Differences in RPE, HR and BL values, between pools and knockouts, were assessed using a paired samples t-test. All statistical analysis was conducted using SPSS version 21 with the level of significance set as $p < 0.05$.

6.3 RESULTS

All data was reliably assessed, with CMJ height, PP and RFD producing ICC's (95% CI) of 0.95 (0.92-0.96), 0.89 (0.85-0.93) and 0.77 (0.69-0.84) respectively; only salivary analyte data was not normally distributed (actual scores for jumps and salivary analytes are presented in appendix D). Scores for RPE, BL and HR are presented in Table 6.1, where values for each are highest in the knockout rounds compared to the pools, however, only is this difference significant in time of bout and RPE. Scores for each variable did not show a trend

of increasing subsequent to each bout. No significant differences were noted between competitions, with the scores for each identified in appendix E.

Table 6.1 Mean (±SD) results from two competitions, separated according to pool and knockout stages

	Time (min)	RPE	BL (mmol/L)	HRave (bpm)	HRmax (bpm)	>80%HRmax
Pools	5.33 ± 2.15	5.7 ± 1.3	3.1 ± 1.4	168 ± 8	192 ± 7	68%
Knockout	15.09 ± 5.24*	8.5 ±1.3*	3.6 ± 1.0	171 ± 5	195 ± 7	74%

Key: Time = length of bout in minutes; RPE = rating of perceived exertion; BL = Blood lactate; HRave = average heart rate (HR); HRmax = maximum HR; >80%HRmax = percentage of time spent above 80% of HRmax. * = Significantly different from pool bouts.

Jump scores (height, PP and PRFD) increased throughout the competition and dropped thereafter. For jump height and PP, the post-knockout score was significantly higher than pre-competition scores and all scores taken at competition were significantly higher than post-competition scores. For PRFD, no significant differences were noted (Figure 6.1).

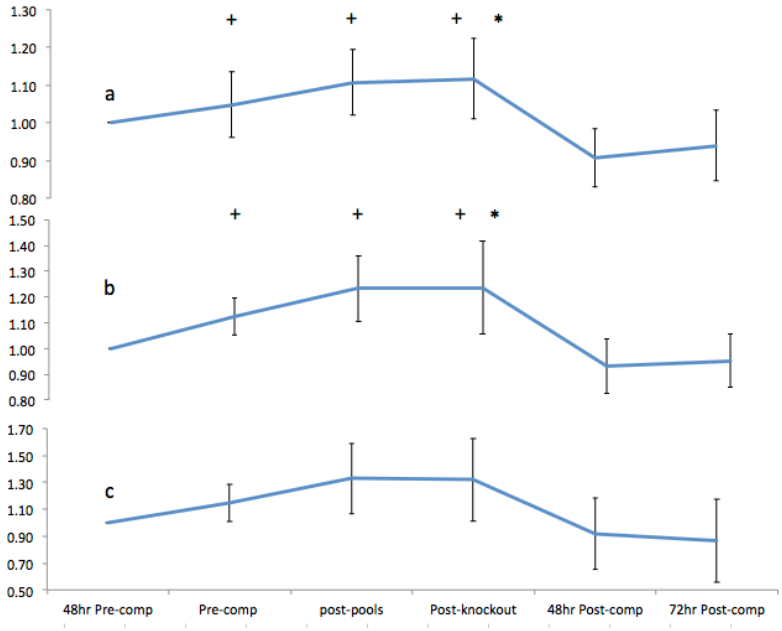

Figure 6.1 Changes in countermovement jump height (Fig 6.1a), peak power (Fig 6.1b) and peak rate of force development (Fig 6.1c) averaged across two competitions (comp), and presented as fold increases from 48hr pre-comp scores. For jump height and peak power, the post-knockout score was significantly higher than all pre-comp scores and all scores taken at comp were significantly higher than post-comp scores. No significant differences were noted in peak rate of force development. * = Significantly different from baseline and pre-comp; + = significantly different than post-comp scores

Scores for the tested salivary analytes and associated ES values and descriptors are presented in Figure 6.2. While C, T and sAA show a tendency to increase during competition and drop thereafter, SIgA and T:C doing the opposite, no significant differences are noted across time-points for any biomarker (Figure 1a – e). ES analysis however, did reveal "large" changes in C and T:C, "moderate" changes in SIgA and sAA and "small" changes in T.

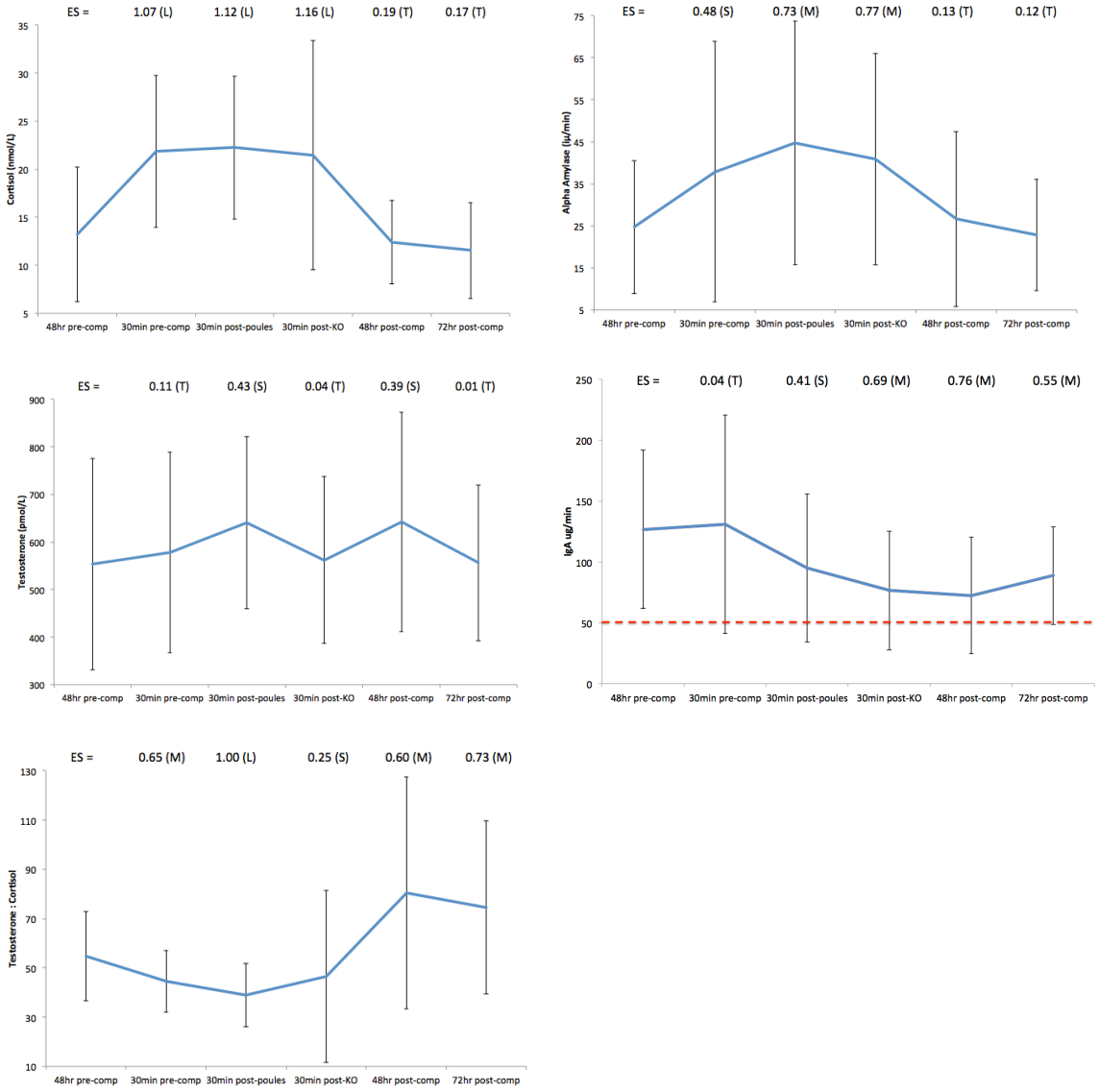

Figure 6.2. While cortisol (Fig 1a), testosterone (Fig 1b) and salivary alpha amylase (Fig 1d) show a tendency to increase during competition and drop thereafter, testosterone to cortisol ratio (Fig 1c) and secretory IgA (Fig 1e) doing the opposite, no significant differences are noted across time-points for any of the measured salivary analytes. Magnitude of change is identified using effect size (ES) analysis and interpreted according to Rhea (2004), where T = trivial, S = small, M = moderate and L = Large. ES scores represent changes from 48 hours pre comp. Error bars represent the standard deviation.

6.4 DISCUSSION

This is the first study to monitor the physiological intensity of a fencing competition and the time course restoration of its inherent fatigue; this information can inform the training programme design of these athletes. Scores for RPE, BL and HR (max and > 80% max) were highest in the knockouts compared to the pools (see Table 7.1), with differences in perceptions of RPE being significantly different between the two. Changes in CMJ height, PP and PFRD increased throughout the competition including immediately after, and significantly so in jump height and PP (Figure 6.1); scores declined thereafter. Changes in salivary analyte release were not significantly different throughout the week (48hrs pre and 72 hours post competition), although C, T and sAA show a tendency to increase during competition and drop thereafter, SIgA and T:C doing the opposite, no significant differences are noted across time-points for any biomarker. ES analysis however, did reveal "large" changes in C and T:C, "moderate" changes in SIgA and sAA and "small" changes in T. Therefore the alternative hypothesis is not supported, as no significant measure of fatigue was found and while on average fencers operate under the threshold for OBLA, they do at times surpass it; this should therefore be trained.

6.4.1 Competition intensity

Results suggest that fencing (foil) is a high-intensity anaerobic sport, and for the most part, relies on alactic energy sources (i.e., phosphocreatine). That said, the spread of data (i.e., the SD) suggests that some bouts (both pools and KO's) evoke BL values of ≥ 4 mmol/L and thus derive energy from anaerobic glycolysis.

A large percentage of pool and KO bouts are spent above > 80% HRmax (68 and 74% respectively), which is surprising given the length of each (5.33 and 15.09 min respectively).

However, given the ample opportunity for rest within foil fencing, with work to rest ratios reported as 1 : 3 (5 s work to 15 s rest) (Roi & Bianchedi, 2008), this may not be a surprising finding and may also explain how BL values, on average, remained < 4 mmol/L. Although only an anecdotal observation, fencers can also prolong within-bout rest periods through methods such as "fixing" the equipment responsible for electronic scoring, realigning swords, and tampering with protective clothing for example. It should also be noted that a fencing competition lasts around 10 hours (Roi & Bianchedi, 2008), but actual bout time only accounts for about 5% of this, and there can be anywhere between 15 and 180 minutes between bouts (Roi & Bianchedi, 2008). Therefore there is also sufficient opportunity to rest and recover between bouts, which one would assume if done correctly, would provide adequate time (given the brevity of bouts) to alleviate much of the residual fatigue. Finally, scores for RPE, HR and BL did not show a trend to increase following each bout; if an accumulation of fatigue was present, this may be an expected observation. It is more likely that the opponent dictates each bout's intensity. Bouts that are won or lost easily would be less intense than those that are evenly matched and thus last longer, also possibly evoking psychological emotions around the uncertainty of the result. As aforementioned, it may also be that there is enough breaks between bouts to not carry over residual fatigue regardless of opponent.

6.4.2 Neuromuscular fatigue

Due to the expected muscle damage and thus soreness associated with fencing, assumed on the basis of performing a high frequency (140 per competition) of lunges (Roi & Bianchedi, 2008), with associated high landing forces and eccentric muscle force (Guilhem, Giroux, Chollet, & Rabita, 2014), CMJ scores were expected to drop throughout the competition and remain below baseline for as long as 72 hours after (Mclellan & Lovell, 2010). In fact, CMJ

height, PP and PRFD actually increased during competition and immediately after (significantly so in the former two), and did not significantly drop below baseline values in the three days following competition. Therefore results here actually found a potentiating effect of competition, presumably linked to body temperature (Wright, Hull, & Czeisler, 2002) and the psychological arousal and concomitant excitability of the nervous system (French, et al., 2007; Clausen, 1986; Viru & Viru, 2003; Viru, Viru, & Bosco, 2003); both of which outweighed fatigue. Assuming that this observation is indeed the case, then the CMJ may not be indicative of muscle damage, and fencing competitions do not involve significant central nervous system fatigue, in fact the opposite is true. Support for this may be gleaned for HR, BL and RPE scores, which as aforementioned did not show a trend to increase with each bout. Perhaps coupled with CMJ data, they do not support any suggestion that a fencer's performance is affected by an accumulation of fatigue.

6.4.3 Salivary analysis

Cortisol and Testosterone are considered valid markers of training load (Cormack, Newton, & McGuigan, 2008; Mclellan & Lovell, 2010), with the latter described as the primary anabolic marker for protein signaling and muscle glycogen synthesis, and the former a stress hormone which mediates catabolic activity, increasing protein degradation and decreasing protein synthesis in muscle cells (Cormack, Newton, McGuigan, & Cormie, 2008). Cortisol is also associated with anxiety, depression and creatine kinase, which is a marker of muscle damage (Kraemer, et al., 1993). The non-significant increases in cortisol levels noted herein are in contrast to that reported in rugby league (Mclellan & Lovell, 2010), rugby union (Elloumi, Maso, Michaux, Robert, & Lac, 2003), soccer (Kraeme et al., 2004) and American football (Hoffman, et al., 2002) for example. However, it is clear that values did increase and when considering that the within competition measurements would typically be lower than

morning measurements on account of diurnal variation, the increases become more apparent – these assertions are supported by the large changes noted during competition as revealed by ES analysis (Fig 6.2a). The individual variation and high variability of scores between athletes also left it unlikely that statistically significant differences would be noted. Furthermore, given our findings regarding actual exercise duration, results are in support of Hill *et al.,* (2008) who found that while increases in C are dependent on exercise intensity (≥60% of maximal oxygen uptake), the secretory limit is also dependant on exercise duration, at least 20–30 min is required. While above this relative threshold large elevations in blood C levels can occur, insignificant changes are noted below this. However, increases in C have also been found in a kickboxing (Moreira, Arsati, & Lima-Arsati, 2010) and wrestling (Coelho, Keller, & da Silva, 2010) match. While this may be on account of muscle damage and most likely based on the psychological stress and arousal of combative competition, the rise in cortisol has also been suggested to coincide with the onset of blood lactate accumulation (Ratamess, et al., 2005; Port, 1991) and our findings reveal that on average, they operate under this threshold. Collectively these findings also support the (non-significant) changes found in T, which share similar volume load thresholds to C (Linnamo, Pakarinen, Komi, Kraemer, & Häkkinen, 2005; Lu, et al., 1997). Furthermore, T release has been found to correlate to a high strength training age (i.e., ≥ 2 years strength training experience) (Kraemer, et al., 1992) and strength capacity (e.g., being able to back squat ≥ 2 times body weight) (Crewther, Cook, Gaviglio, Kilduff, & Drawer, 2012), factors that the tested athletes did not meet. Given these findings, T:C providing an indication of the anabolic/catabolic balance in response to training and competition (Cormack, Newton, & McGuigan, 2008; Meeusen, Piacentini, & Busschaert, 2004), also provided no significant changes. In fact, T:C increased after competition, largely on account of the drop in cortisol; this drop may be attributed to the removal of competition anxiety (Kraemer, et al., 1993).

Again, given that T and C exhibit diurnal variations whereby concentrations are typically higher in the morning and drop throughout the day (Lejune-Lenain, Van Cauter, Desir, Beyloss, & Franckson, 1987), it may be that there was some elevation in recorded levels, but these were offset by the natural decline in release patterns occurring late in the afternoon and evening, when samples were taken at competition. Finally, post competition sores are not indicative or athletes requiring extended recovery periods beyond 72 hours post comp.

sAA monitoring, like C, reflects the stress response to psychological and physical stress (Nater, et al., 2006; Nater, et al., 2005; Kivlighan & Granger, 2006; Granger, et al., 2006). However, unlike C which represent the slower endocrine response to stress (i.e., release via the hypothalamus-pituitary-adrenal axis), sAA represents the faster activation of the sympathetic branch of the autonomic nervous system (ANS) and the release of catecholamines (Chrousos & Gold, 1992); collectively therefore, they may provide a more precise prescription of training and recovery cycles in athletes (Papacosta & Nassis, 2011). Unlike C, which is transported from blood to saliva, sAA is produced locally in the salivary glands and controlled by the autonomic nervous system (Chatterton, Vogelsong, Lu, Ellman, & Hudgens, 1996; Skosnik, Chatterton, Swisher, & Park, 2000), and given that physical exercise causes activation of the sympathetic nervous system, it is expected that sAA will display increases in response to exercise (Kivlighan & Granger, 2006). Such observations have been reported previously as aforementioned. Again, increases in sAA appear mostly dependent on exercise intensity (Bishop & Gleeson, 2009) with a relationship between measures of sAA and blood lactate also reported (de Oliveira, Bessa, & Lamounier, 2010; Calvo, et al., 1997); perhaps these findings support why we did not note significant changes. That said, changes were regarded as moderate, but again we should note that sAA exhibits a pronounced decrease within 60 min after awakening and a steady increase of activity during

the day (Nater & Rohleder, 2009). We must therefore acknowledge that scores may have increased simply due to this.

SIgA functions as the first line of defence to viral pathogens entering the body via mucosal surfaces (Mazanec, Nedrud, & Kaetzel, 1993), thus acting to prevent infections of the upper respiratory tract. Nieman (1994) reported a "J-shaped" relationship between training load and susceptibility to URTI's, where decreases in SIgA accompany a high training load (Neville, Gleeson, & Folland, 2008; Libicz, Mercier, Bigou, Le Gallais, & Castex, 2006; Novas, Rowbottom, & Jenkins, 2003; Gleeson, McDonald, & Pyne, 1999) thus increasing its incidence; low levels of physical activity also increase risk whereas moderate levels provide a protective effect. Short bouts (< 30 min) of high intensity exercise (> 80% VO2max) have also been found to increase SIgA concentration (Bishop & Gleeson, 2009; Nieman, 1994) and typically, assuming testing does not follow strenuous long-term training, SIgA recovers within 24 h post-exercise (Bishop & Gleeson, 2009). Here and albeit non-significant, SIgA showed moderate decreases during the competition, which had not returned to baseline 72 hours later. Also, considering SIgA is subject to a morning nadir in circadian release patterns, with levels rising throughout the day (Dimitriou, Sharp, & Doherty, 2002) and coupled with large increases in the immunosuppressive hormone C, findings appear more meaningful. That said it may not be until SIgA levels drop below 40% of baseline values that athletes are at greater risk of illness and infection and a so called "open window" is thus exposed (Neville, Gleeson, & Folland, 2008). On average, SIgA concentrations never dropped below 40% of baseline values. However, on an individual basis, 6 of the 9 athletes did on at least one occasion, with 2 athletes remaining below this threshold throughout testing. Finally even at 72 hourts post competition, secretory rates are still below basline and thus caution should be exerted. That said, the spread of data does not support the likelihood of many athletes with "open windows".

6.4.4 Study Limitations

The assessed salivary measures are subject to circadian changes, either peaking in the morning and dropping throughout the day or vice versa. Therefore given that samples were collected throughout the day (given the nature of the competition), this effect could not be controlled. For example, while T and C plateau during competition, this may in actual fact represent an increase as, especially post knockout bouts when the local time would be ~ 7 pm, T and C values would be expected to be lower. Furthermore, while all fencers made it through to the knock out stages and across the two competitions three made it to the finals, they each experienced varying success, with some being knocked out immediately and others progressing to the next rounds. Also, salivary samples, unlike measures of RPE, HR and BL, were only taken post pools and knockouts; therefore scores more reflect their final bout, with the intensity dependent on the quality of opposition. In summary, as well as the time of collection again complicated due to competition progression, some fencers would be more fatigued and aroused than others, which would have been lost in the averaging of scores. Future research may better serve the strength and conditioning coach through adopting more case study type approaches.

6.5 Conclusion and Practical Applications

The between bout timings of a fencing competition are unpredictable as is the quality of opposition, thus it is advisable to prepare athletes for the worst-case scenario; a short break followed by a maximum point bout (i.e., 29 hits) on account of an evenly contested bout. In this scenario, RPE is likely to be > 8 and BL > 4 mmol/L, and given the nature of the fight, high-intensity interval training is recommended in preparation for this, ensuring that athletes are exposed to high concentrations of BL, building a buffering capacity and tolerance of

hydrogen ions as a consequence.

Our results do not appear to show that fencing competitions evoke measurable central fatigue. Instead, fencing may be more associated with peripheral and metabolic fatigue, on account of (hypothesised) muscle damage and fuel depletion (predominately phosphocreatine and glycogen). However, the format of a fencing competition provides ample opportunity for recovery, and if recovery strategies are implanted appropriately, could be capable of sufficiently reducing any fatigue. Although conjecture, strategies around fuel replacement (i.e., nutrition) and methods shown to reduce muscle damage and subsequent inflammation (but not concomitantly reducing force output noting the proximity of bouts) may prove most beneficial. Ensuring athletes taper appropriately leading in to a competition should also act to ensure there is no residual training fatigue to carry-over to competition. Within competition recovery strategies should be investigated further.

The hormonal response to competition did not significantly alter, including during the recovery days that followed. This may be a consequence of the rested state the athletes entered the competition, noting that these were the first two competitions of the season (this may not be the case towards the end of the season), or it may be that the athletes were well tapered going in to the competition and were provided with an appropriately reduced volume load of training following it. Of course, it is appropriate to conclude that the intensity of each bout (and also noting no accumulation of fatigue with subsequent bouts was detected) may simply be below the threshold to evoke a significant release of these analytes. In either case, despite the long days associated with fencing competitions including multiple bouts, we did not find any reason to prolong recovery beyond typical recommendations of 3-5 days

depending on intensity. Future research should investigate indices of peripheral fatigue e.g., muscle damage and soreness.

Chapter 7

STUDY FOUR. MONITORING TRAINING LOAD, FATIGUE AND INTENSITY IN OLYMPIC FENCERS

7.1 INTRODUCTION

Athletic training is designed to improve competition performance, which, in addition to sports related skills and decision-making processes, is sought through adaptations in physical capacity. These adaptations are targeted through various exercise and volume-load prescriptions, all integrated into a well-designed training programme. While conditioning sessions or those around developing the fitness of athletes must at least mimic if not surpass that of the competition, there is a fine line between adequate frequency of these to evoke positive adaptations, and enough rest to dissipate fatigue, allowing the adaptations to take place (Meeusen, et al., 2013). At times, the dissipation of fatigue by virtue of appropriate periodization, taking the form of recovery sessions and varied training modalities, is overlooked. Not only will fatigue stunt adaptations (Stone, et al., 1999), but it is also associated with increased risk of injury (Gabbett, 2004), illness (Neville, Gleeson, & Folland, 2008) and reductions in both competition and training performance (Elloumi, Makni,, Moalla, Bouaziz, Tabka, & Chamari, 2012). Collectively these are suggestive of the importance of not just monitoring training intensity, but also fatigue. These values should be compared to competition data as well as the athlete's ability to tolerate training with respect to contraindications such as mood, changes in sleep, injury and illness (Meeusen, et al., 2013). Values to determine athlete fatigue can be judged against scores from physiological tests when the athlete was considered well rested and in good health (Halson, Bridge,

Meeusen, Busschaert, Gleeson, & Jones, 2002; Robson-Ansley, Blannin, & Gleeson, 2007; Achten, Halson, Moseley, Rayson, Casey, & Jeukendrup, 2004).

Because training volume-load is accumulated through various exercise modes (e.g., sports, gym and conditioning training), comparing these can be an issue due to their different units of measurement. As such, measuring session intensity using the session rating of perceived exertion (sRPE) and multiplying this value by the training duration, has become a popular method and is deemed valid and reliable across a multitude of team sports (Alexiou & Coutts, 2008; Coutts, Reaburn, Murphy, Pine, & Impellizzeri, 2003; Gabbett, 2004; Manzi, D'Ottavio, Impellizzeri, Chaouachi, Chamari, & Castagna, 2010), taekwondo (Haddad, Chaouachi, Castagna, Wong, Behm, & Chamari, 2011), swimming (Wallace, Slattery, & Coutts, 2009), boxing (Uchida, et al., 2014) and sprint kayak (Borges, Bullock, Duff, & Coutts, 2014); the score is in arbitrary units (AU) and is termed training load (TL). These scores are collected daily and compared to general indicators of sports performance (to identify any TL's that negatively affected recovery and subsequent injury, illness or training intensity), such as countermovement jump height and the reactive strength index (Cormack, Newton, & McGuigan, 2008; Mooney, Cormack, O'Brien, Morgan, & McGuigan, 2013; Johnson, Gibson, Twist, Gabbett, MacNay, & MacFarlane, 2013; Coutts & Duffield, 2010), as well as perceptions of wellbeing as recorded via questionnaires (Mclellan & Lovell, 2010; Buchheit & Laursen, 2013; Elloumi, Makni,, Moalla, Bouaziz, Tabka, & Chamari, 2012). Jump based tests are considered indicative of neuromuscular fatigue and muscle soreness (Cormack, Newton, & McGuigan, 2008; Mooney, Cormack, O'Brien, Morgan, & McGuigan, 2013; Johnson, Gibson, Twist, Gabbett, MacNay, & MacFarlane, 2013; Coutts & Duffield, 2010), and questionnaires highlight stressors that are contributory to the causes of, and

manifestations of, fatigue (Mclellan & Lovell, 2010; Buchheit & Laursen, 2013). All tests are considered quick and reliable and thus suit the practicalities of applied sport science support. In all cases, where scores drop below baseline, the athlete is considered fatigued and thus requires adjustment to the days TL (Halson, Bridge, Meeusen, Busschaert, Gleeson, & Jones, 2002; Robson-Ansley, Blannin, & Gleeson, 2007; Achten, Halson, Moseley, Rayson, Casey, & Jeukendrup, 2004).

When comparing conditioning sessions and competition data, sRPE scores are generally supported by heart rate (HR) and blood lactate (BL) readings (Foster, et al., 2001; Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004). Whilst the former is quicker and freely available, the latter two are considered gold standard at objectively determining intensity in exercises taxing aerobic and anaerobic (glycolytic pathway) metabolism (Foster, et al., 2001; Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004). In general however, as the measured activity becomes more anaerobic, the association between sRPE and HR is reduced and eventually, when highly anaerobic, non-convergent (Haddad, Chaouachi, Castagna, Wong, Behm, & Chamari, 2011; Coutts, Rampinini, Marcora, Castagna, & Impellizzeri, 2009). Therefore, for high-intensity sports such as fencing that also tax anaerobic glycolysis (Wylde, Frankie, & O'Donoghue, 2013; Guilhem, Giroux, Chollet, & Rabita, 2014), it may be that sRPE is a better measure. These data describe the internal workload of the athlete, and provide an indication of the extent to which aerobic capacity, anaerobic power and hydrogen-buffering capacity should be developed.

The aim of this study was twofold. Firstly to describe the daily TL of the Great Britain fencing squad and how this impacted general performance indicators (jump scores and

wellbeing); an analysis of this data, coupled with a "reflective" account, would help to establish the validity of this process along with its applicability to the elite-sport training environment. Secondly, was to compare conditioning sessions and competition data to check that intensity in the former was highest, and how these sessions are best arranged within the training week, given the high fatigue that was hypothesised to be generated by them. Anecdotal evidence led to the following hypotheses:

Alternative hypothesis: Sparring in training, where athletes regularly face the same opponent and are not faced with the same "knock-out" pressure or win reward, would see training intensity less than competition intensity. Also, given previous research, relatively high TL's would reduce the following morning's measures of jump height and wellbeing.

Null hypothesis: The intensity of sparring would be higher than that of competition and measures of "readiness to train" including questionnaires and jump data, would not be sensitive enough to detect fatigue.

7.2 METHODS

7.2.1 Participants

Eight male fencers from the Great Britain Fencing Squad (foil) took part in the study. On average (mean ± SD), fencers were 21.83 ± 2.32 years of age, 179.23 ±5.51 cm tall, 74.20 ± 6.35 kg in mass, and had 14.25 ± 3.63 years fencing experience, with two having competed in the London 2012 Olympic games. The Middlesex University Ethics Committee approved

the study and each participant provided written informed consent before taking part in the research. All participants were familiar with the testing protocol.

7.2.2 Testing

Readiness to train Questionnaire and the bases of its development. The RTQ was used as the author's previous work within professional sport, coupled with experience in working with the current cohort, identified that the use of established and previously validated questionnaires (see chapter two) was not practically viable for daily use; generally on account of them taking too long to complete. This has also led to the use of short (~ 8 questions, using a 5 or 7 point likert scale) questionnaires in several recent papers (Mclellan & Lovell, 2010; Buchheit & Laursen, 2013; Elloumi, Makni,, Moalla, Bouaziz, Tabka, & Chamari, 2012; Chatard, Atlaoui, & Pichot, 2003; Atlaoui, Duclos, & Gouarne, 2004), with each questionnaire highlighting key indicators of training preparedness and fatigue, and seemingly based on the intuition of the respective research team (Mclellan & Lovell, 2010; Buchheit & Laursen, 2013). Furthermore, others have indicated that questionnaires may be best used as an effective means to educate athletes on the components of recovery and make them aware of their behaviours towards them (Kenttä & Hassmén, 2002) - the pros and cons of using non-validated questionnaires is discussed further in section 2.24.7. Given this, the RTQ was designed to concisely identify questions that describe the behaviours and feelings that best promote or are indicative of, high quality training; they may also be considered as general indicators of athlete wellbeing. The questionnaire is illustrated in Figure 7.1. Scores for each component were summed to describe each athlete's readiness to train. Also, because scores for muscle soreness can change daily based on the previous session's intensity and mode of training (Cheung, Hume, & Maxwell, 2003), this variable was also examined independently.

No.	Before training, please rate today's feelings and your recent behaviors	Fantastic! 2	Better than normal 1	Normal 0	Worse than normal -1	Awful! -2
1	Diet, including immediate-post training refueling					
2	Hydration, e.g., replacing sweat loss and avoiding dark urine					
3	Sleep, i.e., did you get enough					
4	Cool-downs or recovery sessions e.g., stretching, foam rolling, massage etc.					
5	Energy levels, i.e., are you ready to go or do you feel tired/sluggish					
6	Muscle soreness e.g., do your legs feel rested or do they feel heavy					
7	Concentration and task efficiency i.e., what is your skill level like					
8	Mood i.e., have you been feeling happy					
9	Home and/or work life i.e., is it relaxed or stressful at the moment					
10	Health, e.g., do you have a sore throat, runny nose, headache etc.					

Figure 7.1 Readiness to train Questionnaire

CMJ, RSI (both collected every morning), TL, HR, and BL were collected and compared as described in chapter three (general methods section). Sparring sessions consisted of fencing either 5 or 15 point matches for the duration of the session. Conditioning sessions consisted of high intensity interval training focusing on either (Monday) high paced footwork sessions utilising the work-to rest ratios of the sport (see chapter three and Table 7.2) or (Friday) a cross-training method consisting of the Wingate test (also known as the Wingate anaerobic test; WAnT) protocol (Bar-Or, 1987) repeated three times with 30 s rest between each (referred to herein as 3WAnT). The structure of a typical week is outlined in Table 7.2. For BL measures, each athlete had their data collected three times for each exercise component, with scores then averaged for purposes of analysis; for HR and TL, all sessions were recorded. HR values for the 3WAnT are not presented, as the goal of this drill was to increase lactate values only.

Table 7.1 High intensity interval training for fencing utilising a 2-4-2m shuttle

Sword	Gender	Work:Rest	Work (s)	Rest (s)	Reps x Sets[a]	COD (n)	Total Distance[b] (m)	Attacks[c](n)
Epee	Male	1:1	15	15	7 x 3	210	672	126
Foil		1:3	5	15	9 x 3	135	432	81
Sabre[d]		1:5	3	15	9 x 3	81	324	54
Epee	Female	2:1	15	8	5 x 3	150	480	90
Foil[e]		1:3	5	15	8 x 3	120	384	72
Sabre[e]		1:5	3	15	8 x 3	72	288	48

[a]One minute rest between sets

[b]Total distance covered assumes 0.75 revolutions (12m) per 3s (sabre), one revolution(16m) per 5s (foil) and 2 revolutions (32m) per 15s (epee)

[c]This statistic is applicable if each shuttle ends with an attacking lunge

[d]Values are based on anecdotal observations of sabre bouts where it is hypothesised that less work, distance and attacks are performed relative to foil

[e]For female foilests and sabreurs, it is hypothesised that less distance and attacks are performed relative to male equivalents as noted when comparing actual competition data of male and female epeeists'. However, work:rest ratios across gender have not changed as this would incur highly speculative inferences.

7.2.3 Statistical analysis

To determine the reliability of CMJ and RSI scores, single measures intraclass correlations (two-way random with absolute agreement) between trials were conducted. The reliability of the questionnaire was assessed using Cronbach's alpha with all questions deemed to describe one factor, wellbeing. The validity and reliability of using sRPE has already been established

with correlations to HR and lactate based methods reported as 0.55 – 0.92 (Foster, Hector, Welsh, Schrager, Green, & Snyder, 1995; Gabbett, 2004; Wallace, Slattery, & Coutts, 2009). A one-way repeated measure ANOVA was used to determine differences between training and competition scores for HR, BL and sRPE, and to determine differences between daily TL. The above statistical analysis was conducted using SPSS version 21 with the level of significance set as $p < 0.05$.

The study also looked to address whether jump tests (CMJ height and RSI) could be used to predict readiness to train and/or scores for muscle soreness and if so, which was the better method. For this, a series of multilevel regression models using MLwiN (version 2.25) (Rasbash, Steele, Browne, & Prosser, 2005) was performed. As in the present study, multilevel analysis is the preferred option when data are hierarchically structured (Hox, 2010), whereby the repeated measures (time; level 1) are nested within athletes (level 2). In line with the research aims herein, multilevel analysis allowed the simultaneous estimation of within-person fluctuations and individual differences. Prior to entering predictor variables into the models, intercept-only models were constructed to identify the intraclass coefficients (ICCs) for each variable, which represented the proportion of variance at the individual difference level, compared to the total variance. Multilevel modelling is warranted when significant variance exists at the within-person and individual difference levels (Hox, 2010). Models were also tested against individual RTQ questions and daily TL entered into level 2 equations as predictors of CMJ and RSI. When analysing the effect of TL on jump performance, RTQ and muscle soreness scores, data was entered such that Monday's TL was assessed against Tuesday scores and so on. Also, as well as using raw scores, jump, RTQ and soreness scores were converted to a percentage of their baseline scores as recorded during the

last week of the familiarization period; here all scores for the week were averaged for each variable. From then on, baseline scores where periodically assessed and adjusted to ensure they represented the athlete's "normal" test performance.

7.3 RESULTS

All data was normally distributed, intraclass correlations demonstrated a high level of reliability between trials of CMJ ($r = 0.92$) and RSI ($r = 0.89$) and Cronbach's alpha revealed a high level of agreement between the questions contained within the RTQ ($\alpha = 0.83$). The average sRPE, duration and TL of each session and day are presented in Table 7.2; the week's TM is also identified – the TL (and also change sin jumps, TQR and muscle soreness) across the entire period is presented in appendix F. Only Wednesday was significantly different ($p < 0.05$) from all other days, with each day demonstrating a mean standard deviation of 280 AU. A significant difference is also noted when comparing scores for soreness for Monday, Tuesday and Wednesday *vs.* Thursday and Friday (Figure 7.2). Using MLWin, no correlations with jump scores, RTQ scores or any of its individual components, e.g., diet, hydration, sleep and muscles soreness were found when expressed as raw scores or as a percentage of its baseline.

Table 7.2 Training load (TL) averaged across sessions and days, calculated as the product of training duration and session rating of perceived exertion (sRPE). Average weekly training monotony (TM) is presented, calculated as average TL divided by average standard deviation (SD). 3WAnT refers to the conditioning session whereby athletes performed the Wingate test three time separated by 30s rest each time.

Day	Session	Duration	sRPE	Session TL	Daily TL
Monday	Gym	50	5	250	710
	Technical fencing	90	4	360	
	Conditioning (footwork)	20	5	100	
Tuesday	Gym and plyometrics	60	5	300	615
	Footwork	30	3	90	
	Sparring (6 x 5 hits)	45	5	225	
Wednesday	Footwork	20	4	80	1130
	Tactical fencing	30	5	150	
	Sparring (5 x 5 hits)	45	6	270	
	Sparring (4 x 15 hits)	90	7	630	
Thursday	Gym and plyometrics	60	5	300	765
	Footwork	15	3	45	
	Sparring (3 x 15 hits)	60	6	360	
	Conditioning (3WAnT)	6	10	60	
Friday	Gym	50	5	250	700
	Footwork	30	3	90	
	Technical	90	4	360	
Saturday	Rest	0	0	0	0
Sunday	Rest	0	0	0	0
Total TL					**3920**
Average daily TL					**560**
SD daily TL					**416**
TM					**1.35**

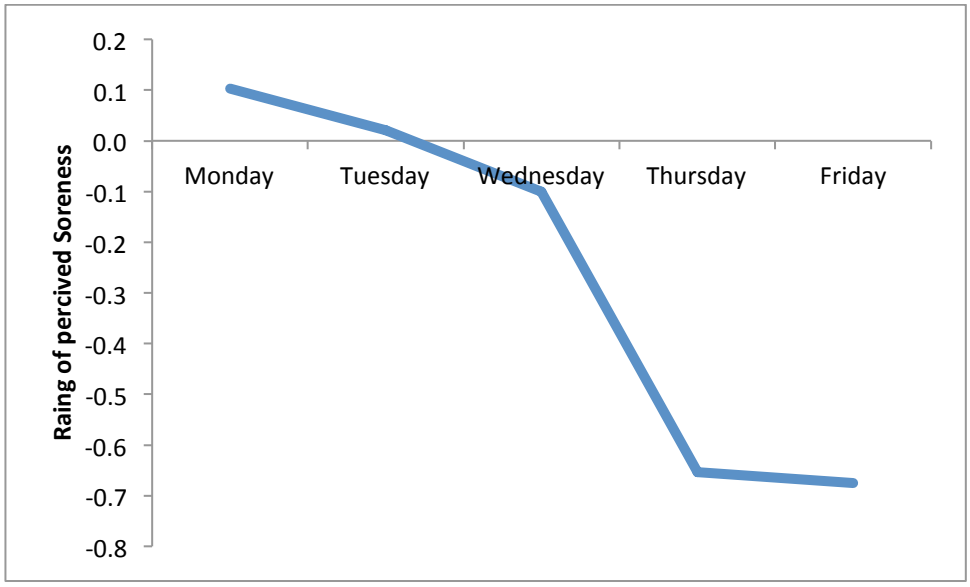

Figure 7.2 Ratings of perceived soreness recorded across the week, noting that Monday, Tuesday and Wednesdays scores are significantly ($p < 0.05$) less than Thursday's and Friday's. A score of zero or more suggests feelings are "normal" or better than normal respectively, while less than zero implies feelings worse than normal.

When comparing HR, BL and sRPE scores between training and competition, significant differences were noted between (1) the sRPE of the 15 point pool bout and the 3WAnT and all other measures (but no difference between these), (2) the BL values of the 3WAnT and all other measures and (3) the time spent above 80% maximum HR (in both the 5 and 15 point bouts) and all other measures. Results suggest that barring the 3WAnT, training intensity is not significantly higher than competition intensity (Table 7.3).

Table 7.3 Average (Ave) scores for sRPE, blood lactate (BL), heart rate (HR) and time of session/bout spent above 80% max HR. 3WAnT refers to the conditioning session whereby athletes performed the Wingate test three time separated by 30s rest each time.

Mode	sRPE	BL (mmol/L)	Ave HR (bpm)	Max HR (bpm)	Percentage of time spent ≥80% Max HR
Pools bouts (5-hits)	5.7 (1.3)	3.1 (1.4)	165 (13)	192 (7)	68*
Elimination bouts (15-hits)	8.5 (1.3)*	3.6 (1.0)	179 (9)	195 (7)	74*
Sparring 5-hits	6.0 (0.9)	2.2 (1.8)	142 (11)	192 (8)	34
Sparring 15-hits	6.6 (1.2)	2.8 (1.6)	140 (13)	192 (9)	40
Conditioning (footwork)	5.4 (1.1)	2.1 (1.6)	178 (5)	195 (3)	46
Conditioning (3WAnT)	8.9 (0.8)*	12.2 (2.1)*	NA	NA	NA

Key: NA = not applicable; * significantly higher than other measures

7.4 DISCUSSION

The data regarding the sensitivity of measures of jump height and wellbeing in reference to their capability to detect fatigue does not support the alternative hypothesis. However, it is supported in terms of sparring not being of sufficient intensity to induce a positive training effect and carryover to competition performance. In summary, results reveal that only Wednesday's TL is significantly higher than the other days, and that scores for soreness are subsequently significantly worse on Thursday and Friday. This may suggest a lack of variation in TL within the training week, as well as identifying a TL (~1130 AU) that causes high levels of muscle soreness that persists for two days (i.e., Thursday and Friday); this may negatively affect training quality. No relationships were found between jumps scores, questionnaire scores or TL, suggesting that these may be independent measures. Also, training intensity was rarely as high, and never significantly higher, than competition

intensity; the exception being BL scores achieved via the 3WAnT. This may suggest that training does not adequately prepare athletes for competition fitness demands.

The scores for daily TL (Table 7.2) suggest that the average week did not follow the conventional arrangement of "hard" day "easy" day (or at least some form of undulation), creating high variability and opportunity for both adaptation and recovery (Bruin, Kuipers, Keizer, & Vander Vusse, 1994). For example, when the TL of such an arrangement is instead equally divided into several consecutive "medium" training days, monotony (and its associated TM score) would be high and the athletes would be at higher risk of illness, OT and naturally, under-performance (Bruin, Kuipers, Keizer, & Vander Vusse, 1994; Foster, 1998). While the intention was to create a varied pattern in TL, it was simply the case that athletes did not rate the session intensity as expected. These findings are consistent with the differences in training programme design by coaches versus execution by athletes (Foster, Daines, Hector, Snyder, & Welsh, 1996) and it is thus important that the athlete rates the session, otherwise a mismatch may occur (Foster, Helmann, Esten, Brice, & Porcari, 2001; Wallace, Slattery, & Coutts, 2009). While no normative values exist regarding the SD of daily TL or the score for TM, subsequent training programmes must ensure increases in the former and decreases in the latter (Foster, et al., 2001). Also, given that scores for muscle soreness (Figure 7.2) sharply and significantly worsened following the Wednesday session, it may be that the TL value of 1130 AU for this day is currently too high for fencers to tolerate given the demand for high quality training the following day; muscle soreness, indicative of muscle damage (or rather myofibrillar disruptions), would reduce maximal voluntary contraction force (Raastad, et al., 2010) and therefore related functions such as jump height (Miyama & Nosaka, 2004) and more specifically, lunge distance and change of direction

speed. Of course the high TL of Wednesday and muscle soreness scores of Thursday may simply be coincidental but this is an association that should be explored further in subsequent studies. Assuming correct, training quality and subsequent adaptations may be compromised and of course every effort should be taken to avoid this.

Part of the aforementioned mismatch was finding that conditioning footwork sessions (using competition based work to rest ratios) and sparring, in general, were not set at an appropriate intensity relative to competition data. In both instances, time spent at ≥ 80% maximum HR, sRPE and BL scores, were lower (and significantly so in the former two) suggesting an inappropriate stimulus. In regard to footwork based conditioning, this may suggest that they are well conditioned for this activity, and without the psychological effects of competition and its (assumed) release of adrenaline for example, intensity was not high enough. With regards to sparring, again the psychological element of competition may not have been high enough but also, the stop-start nature of sparring (largely attributed to electronic scoring systems) further reduced exercise intensity. It is also likely that the intensity of sparring depended on the competition provided by the opponent; matches that are easily won or lost would again reduce bout intensity. Only the 4 x 15 point sparring on the Wednesday produced a relatively high average RPE score of 7, but this, after conversations with the athletes, could be a consequence of it being the last session of the day and further affected by the volume of work during and preceding this. Only the conditioning sessions involving the 3WAnT test provided BL's significantly in excess of competition. This activity was not based on the actions of the opponent nor did it require any competition. Also, it was new to the athletes and thus provided a stimulus they were otherwise unaccustomed to. In support of this non-sport-specific approach, the fencers reported (personal communication) carrying less

residual fatigue to the subsequent sessions. This would likely be on account of stressing different motor units to regular training, the brevity of the exercise, and the likely reductions in muscle soreness given its non-impact format. Assuming true, this would enable the efficacy of technical and tactical sessions to be maximised and fundamentally, not further enhance the risk of overuse injuries in these athletes, which is a prevalent issue (Harmer, 2008). Furthermore, given that the goal was to induce high volumes of lactate (or rather hydrogen ions) in to the lower body, such a method appears more viable as well as being optimal. Higher concentrations of hydrogen ions, despite the method used to induce them, would enhance the buffering capacity of the affected muscles, enhancing mitochondria and capillary density, along with aerobic enzyme activity and associated fuel utilisation (Bishop, Hill-Haas, Dawson, & Goodman, 2006).

No correlations between jump measures (for neuromuscular fatigue) and questionnaire scores were found, a finding in contrast to others (Mclellan & Lovell, 2010; Buchheit & Laursen, 2013; Elloumi, Makni,, Moalla, Bouaziz, Tabka, & Chamari, 2012; Chatard, Atlaoui, & Pichot, 2003; Atlaoui, Duclos, & Gouarne, 2004). There are probably several reasons behind this, not least that they may both be independent scores and may not be measuring what they are purported to. There were continuous changes and adaptations occurring physically and behaviourally by the athletes. While steps were taken to periodically adjust athlete baseline values, it may be that a mismatch in timing occurred between training responses (i.e., adaptations or performance declines) and adjustment to athlete baselines. For example, preseason periods typically induce high levels of fatigue with adaptations presenting themselves several days later, following a decline and the eventual dissipation of residual fatigue. This may highlight that attempting to monitor TL in this context (e.g., pre-season),

when athletes are continually expected to transition between high fatigue (and exhibit reduced test performance) and adaptation phases (and thus improved test performance) is not appropriate. Perhaps monitoring TL is better reserved for in-season periods when the goal is to maintain standards and the athlete's performance is only likely to fluctuate on account of fatigue. Furthermore, the questionnaire itself was intended to act as a cue for beneficial behaviours leading to enhanced recovery. Some of the good practice relevant to this and developed during the previous season would take time to again become habitual; such behavioural modifications are also the goal of pre-season. Therefore there may have been continued changes in behaviours and the athlete's perception of what "normal" for them was or expected to be that were not established again till the end of pre-season.

7.5 CONCLUSIONS AND PRACTICAL APPLICATIONS

The normative data collected will be used to readdress the training week and ensure a "hard" day "easy" day rota; of course it is important to immediately use athlete scores, and allow the programme to be adapted appropriately. Conditioning drills appear to benefit from high intensity interval exercises that are non-sport specific and do not rely on one-on-one competitions. The latter increases stoppages and thus rest time, as well as being largely affected by the opponent. A non-sport specific form also enables a quicker recovery given the variation in recruited motor units. The goal here should be lactate accumulation and where some form of sport specificity is required, sparring should be preceded by a conditioning activity of this type; a theory that requires further analysis. In addition to the 3WAnT, similar drills can (presumably) be implemented using rowing ergometers and ropes for example, thus reducing fatigue carried over to technical sessions as well as the risk of overuse injuries; again this requires further investigation. While no relationship was found between RTQ and

muscle soreness scores and neuromuscular fatigue, it may be prudent to investigate this further during the in-season, when the goal is maintenance and changes to "normal" are not so profound. Also, perhaps changing the questionnaire's likert scale to 1-7 might increase sensitivity and better enable the detection of changes to wellbeing. However, with regards to practical application, one or two questions may need to be removed otherwise there is a risk that athletes will develop contempt towards it.

Chapter 8

CONCLUSIONS, RECOMMENDATIONS AND DIRECTIONS FOR FUTURE RESEARCH

8.1 OVERALL SUMMARY

This thesis describes the scientific investigations undertaken as part of the sport science provision provided to the Great Britain Fencing Team, in the build up to the 2016 Olympic Games in Rio. Collectively these studies enhance knowledge regarding the optimal physical preparation of fencers.

8.1.1 Summary of fencing

In general, fencing involves a series of explosive attacks, spaced by low-intensity movements and recovery periods, predominately taxing anaerobic metabolism. Perceptual and psychomotor skills (i.e., the ability to quickly and appropriately respond to an opponent's actions) prevail, and there is a great need to repeatedly defend and attack, and often, engage in a seamless transition between the two. While a fencing competition may last around 10 hours, only one hour of this is actually spent competing, and again, less than half of this actually represents high-intensity actions. Lunging and changing direction are the most common actions, with fencers covering around 250-1000 m, attacking 140 times, and changing direction nearly 400 times. There is also the requirement to often complete these movements in quick succession, thus a high-intensity, speed-endurance capacity, often challenged by an accumulation of hydrogen ions, is required.

This type performance analysis data is indicative of the "explosive" characteristics required by fencers, the need to maximise lunging (from and out of range position) and change of direction kinetics (noting that kinematics is coach led) and the ability to tolerate and buffer lactate to enable the continued execution of these at maximal intensity. Of course, perceptual, technical and tactical skills prevail, but this is beyond the remit of the sport science team. Also, recovery interventions are fundamental given the long rest periods presented at competition, however, this is beyond the scope of the current research, but certainly fundamental to the continued progression of competition performances. These studies centred on physical preparation, including programming.

8.1.2 Lunging and Change of Direction Speed

Lunging is the most common form of attack. While this must be done as fast as possible leaving the opponent with little time to respond and defend against it, it must also be done from an out of range position. Although lunge distance is most highly correlated to height ($r = 0.45$; $p < 0.05$), which is unsurprising, it is also followed very closely by lower-body power ($r = 0.44$; $p < 0.05$). This suggests that smaller fencers (in stature) can compensate for their reduced "reach" by being more explosive and thus lunging further through power capabilities rather than having longer limbs. Of course a natural deduction is that tall fencers, who are also most powerful, are distinctly advantaged. Perhaps for these reasons, when we look at lunge velocity (i.e., lunge distance divided by the time taken to strike), we only note correlations with lower-body power ($r = 0.51$; $p < 0.05$). It may be that shorter fencers have instinctively compensated in this way and that taller fencers are yet to capitalise. It appears that lunge velocity is determined more by a fencer's lower-body power.

Lower-body power also correlated best with change of direction speed (CODS; r = -0.65; p < 0.05) and was also moderately affected by height (r = -0.37; p < 0.05), the latter likely on account of longer limbs providing longer strides. Unsurprisingly, lower-body power, expressed as horizontal (i.e., the standing broad jump) rather than vertical (i.e., the countermovement jump) displacement, was the best predictor (including lunging), and for both is indicative of the need to use training modalities that have a high transfer (i.e., sport-specificity). CODS was also influenced by reactive strength (r = -0.41; p < 0.05), which given the need for "fast feet" was an expected outcome. Training implications for lunging and changing direction include improving lower-body power, particularly that which is expressed horizontally, and improving reactive strength for the purpose of CODS.

8.1.3 Repeat Lunge Ability

The bout demands for continued and maximal effort lunging, incorporated within a footwork sequence involving changes in direction, was also tested. This form of speed-endurance, referred to as repeat lunge ability (RLA), was influenced most by CODS (r = 0.70; p < 0.05) and lower-body power (r = 0.68; p < 0.05); the latter again more so by the standing broad jump than the countermovement jump (i.e., horizontal *vs.* vertical displacement). Multiple regression analysis revealed that these two variables accounted for 61% of the common variance associated with RLA scores. Based on these findings and as confirmed by the training group, where RLA significantly (p < 0.05) improved along with both CODS and SBJ, RLA may be improved by increasing CODS and lower-body power. Also, given the nature of the RLA test, conditioning drills designed to enable fencers to work at higher intensities before reaching OBLA, as well as working in the presence of hydrogen ion accumulation, may also aid performance.

8.1.4 Effectiveness of Conditioning Drills

Drills designated to improve a fencer's conditioning should look to tax their lactic acid system. Data describing heart rate (HR), blood lactate (BL) and ratings of perceived exertion were measured across two competitions, revealing that on average (± SD), elimination bouts (3 rounds of 3 minutes, one minute rest between rounds) were above 80% HR max for 74% of the bout, RPE was 8.5 ± 1.3 and BL was 3.6 ± 1.0 mmol/L. While sparring and footwork drills (using work to rest ratios of the sport) appear outwardly beneficial, they are not. Respectively, these produce RPE's of 6.6 ± 1.2 and 5.4 ± 1.1, BL's of 2.8 ± 1.6 and 2.1 ± 1.6 mmol/L and the percentage of time above 80% HR max was 40 and 46%. It is hypothesised that the arousal of competition and the level of opponent significantly contribute to these measures and without them training drills are unable to evoke similar values. In summary, there is a discrepancy in physiological intensity between competition and training interventions that must be addressed. Consequently, the non sport specific conditioning drill used in these investigations, consisting of three repetitions of the Wingate test, with 30s rest between bouts, holds merit. This drill produced BL values of 12.2 ± 2.1 mmol/L and RPE's of 8.9 ± 0.8. Similar drills for which the fencer would be unaccustomed to, such as battle ropes and sled pulls are likely to be equally beneficial and can be sequenced to challenge the fencer over a prolonged time, matching that of a bout. These drills are referred to as "off-feet" conditioning and may have the added benefit of reduced soreness (relative to footwork drills) for subsequent fencing sessions. To provide greater carry-over, these drills could be performed in the rest period of training bouts, thus challenging the fencer to compete in a fatigued state which they normally only experience in competitions. These hypotheses, around pre-exhaustive fencing and off-feet conditioning, require further analysis.

8.1.5 Competition Fatigue

Also assessed across two fencing competitions, including subsequent recovery days, were measures of fatigue. Countermovement jump (CMJ) scores and saliva samples, for the assessment of testosterone (T), cortisol, salivary alpha-amylase (sAA) and immunoglobulin A (IgA), were taken. While it was hypothesised that these would show a trend of increasing fatigue, i.e., CMJ, T, sAA and IgA scores reducing, with cortisol increasing, such trends were not noted. No differences were noted across any measured salivary analyte and in actual fact, CMJ scores significantly increased from baseline during competition. The latter may have been on account of body temperature while the former due to insignificant work volumes and intensity. Collectively, scores suggest that fencers should be able to maintain high-intensity fencing throughout a competition, with the efficacy of this based on strategies around rest and recovery. These strategies, usually involving warm-ups and cool-downs and nutritional interventions, should be investigated as part of future research.

8.1.6 Training Programme: monitoring Load and Readiness to Train

Finally, the programming of a fencer's week requires careful consideration, especially given the repetition of similar movements and the impacts associated with heel-strike based lunging; foot strikes for this produce forces in excess of three times bodyweight and are considered responsible for the apparent asymmetry noted in these athletes. Training load (TL), measured as RPE multiplied by session duration, was collected for all sessions across the pre-season period. These were compared to measures of CMJ height and reactive strength index (RSI) and a questionnaire designed to detect athlete wellbeing, ultimately describing readiness to train; all measures were collected every morning before training. While it was expected that increases in TL would see subsequent declines in wellbeing and jump scores, this was not detected, suggesting that this may be an inappropriate monitoring process. It may

also be that continued increases in strength and a better understanding of the recovery process masked its effectiveness. Regarding the latter, the subliminal information received by virtue of simply completing the questionnaire, may have shifted the benchmark for "normal" recovery (which is a scale indicator on the questionnaire). The questionnaire included the athlete's perception of muscle soreness, which did seem indicative of daily TL when assessing Monday's impact on Tuesday, Tuesday's on Wednesday and so on. Here, Monday, Tuesday and Wednesday scores were significantly ($p < 0.05$) less than Thursday's and Friday's. This coincided with a peak in TL for the Wednesday that was assumed to indicate a load, which was too high, and thus negatively affecting subsequent training. The training week should be reorganised to follow a pattern of alternating days between high loads and low loads to ensure fatigue is appropriately managed and does not affect subsequent training days; this conventional arrangement of "hard" day "easy" day creates high variability and opportunity for both adaptation and recovery.

8.1.7 Individual scores *vs.* group averages

Of course when working with athletes, there will be inter-individual variances regarding their response to a training intervention or competition stimuli. It is therefore important to use the athlete's own data in prescribing training programmes. For example, physiological responses in HR and BL during competition and training, despite engaging in identical sessions, will be different, as will their RPE and reported TL. Some fencers will respond well to sessions that others see, and we detect, no benefit from. Such a statement appears to contradict the methodologies used in the current thesis (i.e., where all scores are averaged). However, it must be remembered that the data collected herein, will be used to design a physical training template for British Fencing, and in doing so, describe the strength and conditioning philosophy adopted for these athletes. Therefore it is far more beneficial to generalise the

data from a squad of elite athletes, than it is to produce a training ideology from the response of a single case study. This is further supported when considering that given the open nature of fencing and the significant influence the opponent has to the physiological (and psychological) intensity of training and competing, there may even be large intra-individual variations in measures. The summations of this thesis have enabled the development of a training approach, which previously did not exist and little information was available to develop one for, which can now be implanted and adapted according to the individual response of each fencer.

8.2 CONCLUSIONS AND RECOMMENDATIONS

Fencers should be seen and trained as power-based athletes requiring the ability to work at high-intensity for several consecutive periods, challenging their lactate tolerance. It is important to use conditioning drills that challenge the fitness demands of a bout, as footwork and sparing within training are usually dissimilar to this; here a non-sport specific approach may be required, including using work to rest intervals in excess of actual sports competition. Competition strategies should centre on rest and recovery interventions that help to prepare fencers for inter-bout rest intervals that very between 10 minutes and 2 hours. Fatigue detection measures (i.e., hormonal profiles and jump height) do not show any significant variability across the competition day, if anything, power output actually increases. Therefore appropriate preparation protocols (i.e., warm-ups, cool-downs and nutrition) on the day of competition, coupled with arguably more relevant and enhanced conditioning provided during training, should help improve performances at competition by enabling fencers to consistently work at maximal output throughout all bouts. Finally, given the repetitive nature of fencing actions, training should be tailored to manage the fatigue and overuse injuries that

are prevalent to the sport. A hard-day-easy rota with respect to training load, plus non-sport specific conditioning that acts to provide some level of cross training, should help cater for this.

8.3 LIMITATIONS OF THE RESEARCH

While elite athletes were used within this research, the sample size for this was often small, requiring use of talent development athletes were the sample size was required to extend beyond eight. Also, the results only represent the athletes of the Great Britain fencing team, noting that no data for the Italians or French, regarded as the best fencing nations, was available. Furthermore, there are several training suggestions made within this thesis and while logical in their development, it is often difficult to use appropriate interventions to check their validity. There are natural constraints to working with elite athletes, including no access to a control group and conducting re-testing using time-consuming tests that take athletes, pressured by fencing performances, away from training. Also, some assessments require fencers to report back to the sport science team during actual competitions. Where this detracts from their focus or competition routines, they are understandably less willing. These limitations relate to testing lunging performance, testing within competition variables (i.e., heart rate, jumps, RPE and salivary analytes) and monitoring training readiness using questionnaires and jumps that provided no obvious indication of how training load is best tailored.

8.4 DIRECTIONS FOR FUTURE RESEARCH

Future research, in addition to validating the training suggestions made herein, should look to identify how rest and recovery interventions during competitions can be best tailored to maximise the large between-bout rest periods provided at competition. Also, and not touched on in this thesis, are the how travel, especially across several time zones, as regularly occurs in fencing, can be best managed.

Chapter 9

REFERENCES

Achten, J., & Jeukendrup, A. (2003). Heart rate monitoring: applications and limitations. *Sports medicine , 33* (7), 517–38.

Achten, J., Halson, S., Moseley, L., Rayson, M., Casey, A., & Jeukendrup, A. (2004). Higher dietary carbohydrate content during intensified running training results in better maintenance of per- formance and mood state. *J Appl Physiol , 96*, 1331–40.

Al Haddad, H., Laursen, P., Chollet, D., Ahmaidi, S., & Buchheit, M. (2011). Reliability of resting and postexercise heart rate measures. *Int J Sports Med , 32*, 598-605.

Alexiou, H., & Coutts, A. J. (2008). A comparison of methods used for quantifying internal training load in women soccer players. *International Journal of Physiology and Performance , 3*, 320-330.

Aquili, A., & Tancredi, V. (2013). Performance analysis in sabre. *The Journal of Strength & Conditioning Research , 27* (13), 624-630.

Artioli, G., Gualano, B., Smith, A., Stout, J., & Lancha, A. (2010). Role of beta-alanine supplementation on muscle carnosine and exercise performance. *Medicine and science in sports and exercise , 42* (6), 1162-73.

Asci, A., & Acikada, C. (2007). Power production among different sports with similar maximum strength. *Journal of Strength and Conditioning Research , 21*, 10-16.

Atlaoui, D., Duclos, M., & Gouarne, C. (2004). The 24-h urinary cortisol/cortisone ratio for monitoring training in elite swimmers. *Medicine and Science in Sports and Exercise , 36*, 218-224.

Aubert, A., Seps, B., & Beckers, F. (2003). Heart Rate Variability in Athletes. *Sports Medicine , 33* (12), 889–919.

Aziz, A., Chia, M., & Teh, K. (2000). The relationship between maximal oxygen uptake and repeated sprint performance indices in field hockey and soccer players. *J Sports Med Phys Fitness , 40*, 195-200.

Aziz, A., Mukherjee, S., Chia, M., & Teh, K. (2007). Relationship between measured maximal oxygen uptake and aerobic endurance performance with running repeated sprint ability in young elite soccer players. *J Sports Med Phys Fitness 7: 401–407, 2007. , 7*, 401-407.

Baechle, T., & Earle, R. *Essentials of Strength Trianing and Conditioning* (Vol. 3). Champaign, IL, USA: Human Kinetics.

Baker, D. (2011). Recent trends in high-intensity aerobic training for field sports. *Professional strength and conditioning , 22*, 3-8.

Balsom, P., Ekblom, B., & Sjodin, B. (1994). Enhanced oxygen availability during high intensity intermittent exercise decreases anaerobic metabolite concentrations in blood. *Acta Physiologica Scandinavica , 150*, 455-456.

Balsom, P., Gaitanos, D., Ekblom, B., & Sjodin, B. (1994). Reduced oxygen availability during high intensity intermittent exercise impairs performance. *Acta Physiologica Scandinavica , 152*, 279-285.

Balsom, Seger, J., Sjodin, B., & Ekblom, B. (1992). Maximal-intensity intermittent exercise: effect of recovery duration. *Int J Sports Med , 13*, 528-533.

Bangsbo, J., Krustrup, P., González-Alonso, J., & Saltin, B. (2001). ATP production and efficiency of human skeletal muscle during intense exercise: effect of previous exercise. *Am J Physiol Endocrinol Metab , 280* (6), E956-E964.

Bannister, E. (1991). Modeling athletic performance. In J. D. McDougall, H. A. Wenger, & H. J. Green (Eds.), *Physiological testing of the elite athlete* (pp. 403–424). Champaign: Human Kinetics.

Bar-Or, O. (1987). The Wingate anaerobic test an update on methodology, reliability and validity. *Sports Medicine , 4* (6), 381-394.

Basset, D., & Howley, E. (2000). Limiting factors for maximum oxygen uptake and determinants of endurance performance. *Med Sci Sports Exerc , 32*, 70-84.

Beedie, C., Terry, P., & Lane, A. (2000). The profile of mood states and athletic performance: Two meta-analyses. *Journal of applied sport psychology , 12* (1), 49-68.

Beltzer, E., Fortunato, C., Guaderrama, M., Peckins, M., Garramone, B., & Granger, D. (2010). Salivary flow and alpha- amylase: collection technique, duration, and oral fluid type. *Physiol. Behav , 101* (2), 289-296.

Berger, B., Motl, R., Butki, B., Martin, D., Wilkinson, J., & Owen, D. (1999). Mood and cycling performance in response to three weeks of high-intensity, short-duration overtraining, and a two-week taper. *Sport Psychol , 13*, 444-457.

Berglund, B., & Safstrom, H. (1994). Psychological monitoring and modulation of training load of world-class canoeists. *Medicine and Science in Sports and Exercise , 26*, 1036-1040.

Billat, V., Sirvent, P., Py, G., Koralsztein, J., & Mercier, J. (2003). The concept of maximal lactate steady state. *Sport Med , 33*, 406-426.

Bird, S. (2013). Sleep, Recovery, and Athletic Performance: A Brief Review and Recommendations. *Strength & Conditioning Journal , 35* (5), 43-47.

Bishop, D., Davis, C., Edge, J., & Goodman, C. (2004). Induced metabolic alkalosis affects muscle metabolism and repeated-sprint ability. *Med Sci Sports Exerc , 36*, 807-813.

Bishop, D., Edge, J., & Goodman, C. (2004). Muscle buffer capacity and aerobic fitness are associated with repeated-sprint ability in women. *Eur J Appl Physiol , 92*, 540-547.

Bishop, D., Hill-Haas, S., Dawson, B., & Goodman, C. (2006). Comparison of muscle buffer capacity and repeated-sprint ability of untrained, endurance-trained and team-sport athletes. *European journal of applied physiology , 96* (3), 225-234.

Bishop, N., & Gleeson, M. (2009). Acute and chronic effects of exercise on markers of mucosal immunity. *Front Biosci , 14* (2), 4444-56.

Bobbert, M., & Casius, L. (2005). Is the countermovement on jump height due to active state development? *Medicine and Science in Sports and Exercise , 37*, 440-446.

Bogdanis, G., Nevill, M., Boobis, L., Lakomy, H., & Nevill, A. (1995). Recovery of power output and muscle metabolites following 30 s of maximal sprint cycling in man. *J Physiol , 482* (2), 467-480.

Bompa, T., & Haff, G. (2009). *Periodiasation. Theory and methodology of training* (5th Edition ed.). Champaign, IL, USA: Human Kinetics.

Boobis, L., Williams, C., & Wooton, S. (1982). Human muscle metabolism during brief maximal exercise in man. *J Physiol , 338*, 21-22.

Borg, G. (1982). Psychophysical Bases of Perceived Exertion. *Medicine and Science in Sports and Exercise , 14* (5), 377–381.

Borges, T., Bullock, N., Duff, C., & Coutts, A. (2014). Methods for quantifying training in Sprint Kayak. *Journal of Strength and Conditioning Research , 28* (2), 474-482.

Bosch, J., Veerman, E., de Geus, E., & Proctor, G. (2011). α-Amylase as a reliable and convenient measure of sympathetic activity: don't start salivating just yet! *Psychoneuroendocrinology , 36* (4), 449-453.

Bosquet, L., Gamelin, F., & Berthoin, S. (2008). Reliability of postexercise heart rate recovery. *International Journal of Sports Medicine , 29* (3), 238 - 243.

Bottoms, L., Sinclair, J., Gabrysz, T., Szmanthan-Gabrysz, U., & Price, M. (2011). Physiological responses and energy expenditure to simulated epee fencing in elite female fencers. *Serbian journal of sports sciences , 5* (1), 17-20.

Bouget, M., Rouveix, M., Michaux, O., Pequignot, J. M., & Filaire, E. (2006). Relationships among training stress, mood and dehydroepiandrosterone sulphate/ cortisol ratio in female cyclists. *Journal of Sports Science , 24* (12), 1297–1302.

Brink, M., Visscher, C., Arends, S., Zwerver, J., Post, W., & Lemmink, K. (2010). Monitoring stress and recovery: new insights for the prevention of injuries and illnesses in elite youth soccer players. *British journal of sports medicine , 44* (11), 809-815.

Brooks, G., Fahey, T., & Baldwin, K. (2005). *Exercise Physiology: Human Bioenergetics and Its Applications* (4th edition ed.). New York: McGraw-Hill Higher Education.

Bruin, G., Kuipers, H., Keizer, H. A., & Vander Vusse, G. J. (1994). Adaption and overtraining in horses subjected to increasing training loads. *Journal of Applied Physiology , 76*, 1908-1913.

Buchheit, M. (2008). Field tests to monitor athletic performance throughout a team-sport season. *Science in Sports , 23*, 29–31.

Buchheit, M. (2008b). The 30–15 intermittent fitness test: accuracy for individualizing interval training of young intermittent sport players. *Journal of Strength and Conditioning Research , 22*, 365–374.

Buchheit, M., & Laursen, P. (2013). High-Intensity Interval Training, Solutions to the Programming Puzzle. *Sports medicine , 43* (5), 313-338.

Buchheit, M., Chivot, A., Parouty, J., Mercier, D., Al Haddad, H., Laursen, P. B., et al. (2010). Monitoring endurance running performance using cardiac parasympathetic function. *European Journal of Applied Physiology , 108*, 1153–1167.

Buchheit, M., Millet, G., Parisy, A., Pourchez, S., Laursen, P., & Ahmaidi, S. (2008). Supramaximal training and postexercise parasympathetic reactivation in adolescents. *Medicine and Science in Sportsand Exercise , 40* (2), 362.

Buchheit, M., Papelier, Y., Laursen, P., & Ahmaidi, S. (2007). Noninvasive assessment of cardiac parasympathetic function: postexercise heart rate recovery or heart rate variability? *American Journal of Physiology-Heart and Circulatory Physiology , 293* (1), H8-H10.

Calvo, F., Chicharro, J., Bandres, F., Lucia, A., Perez, M., Alvarez, J., et al. (1997). Anaerobic threshold determination with analysis of salivary amylase. *Can. J. Appl. Physiol , 22*, 553—561.

Carey, D., Drake, M., Pliego, G., & Raymond, R. (2007). Do hockey players need aerobic fitness? Relation between VO2max and fatigue during high-intensity intermittent ice skating. *J. strength Cond. Res , 23*, 963-966.

Castagna, C., Manzi, V., D'Ottavio, S., Annino, G., Padua, E., & Bishop, D. (2007). Relation between maximal aerobic power and the ability to repeat sprints in young basketball players. *J. Strength Cond. Res , 21* (4), 1172-1176.

Castle, E. (2003). *Schools and Masters of Fencing. From the Middle ages to the Eighteenth Century.* Mineola, New York: Dover publications.

Cerizza, C., & Roi, G. (1994). Aspetti Fisiologici dell'attivita sportive di base, le carratteristiche fondamentali del giovane schermidore. In G. Roi, & D. (. Bianchedi, *The Science of Fencing. Implications for performance and injury prevention. Sports Medicine. 38(6)* (pp. 465-481).

Chard, T. (1990). *An introduction to radioimmunoassay and related techniques* (4th edition ed.). Amsterdam, Holland: Elsevier.

Charles, S., Fulco, C., Lewis, S., Frykman, P., Boushel, R., Smith, S., et al. (1996). Muscle fatigue and exhaustion during dynamic leg exercise in normoxia and hypobaric hypoxia. *J Appl Physiol , 81* (5), 1891-1900.

Chatard, J., Atlaoui, D., & Pichot, V. (2003). Training follow up by questionnaire fatigue, hormones and heart rate variability measurements. *Science in Sports , 18*, 302-304.

Chatterton, R., Vogelsong, K., Lu, Y., Ellman, A., & Hudgens, G. (1996). Salivary alpha-amylase as a measure of endogenous adrenergic activity. *Clin. Physiol , 16*, 433-448.

Cheung, K., Hume, P., & Maxwell, L. (2003). Delayed onset muscle soreness. *Sports Medicine , 33* (2), 145-164.

Chiodo, S., Tessitore, A., & Cortis, C. (2011). Stress-related hormonal and psychological changes to official youth taekwondo competitions. *Scand J Med Sci Sports , 21*, 111-119.

Chrousos, G., & Gold, P. (1992). The concepts of stress and stress system disorders: overview of physical and behavioral homeostasis. *Jama , 267* (9), 1244-1252.

Clarkson, P., Nosaka, K., & Braun, B. (1992). Muscle function after exercise-induced muscle damage and rapid adaptation. *Medicine and Science in Sports and Exercise , 24* (5), 512-520.

Clausen, T. (1986). Regulation of active Na+-K+ transport in skeletal muscle. *Physiol. Rev , 66*, 542-580.

Clow, A., Thorn, L., Evans, P., & Hucklebridge, F. (2004). The awakening cortisol response: methodological issues and significance. *Stress: The International Journal on the Biology of Stress , 7* (1), 29-37.

Coelho, R., Keller, B., & da Silva, A. (2010). Effect of pre- and postcompetition emotional state on salivary cortisol in top-ranking wrestlers. *Percept Mot Skills , 111* (1), 81-6.

Cohen, J. (1992). A power primer. *Psychological bulletin , 112* (1), 155.

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences* (Vol. 2). Psychology Press.

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences* (2nd Edition ed.). New Jersey: Lawrence Erlbaum.

Comyns, T., & Flanagan, P. (2013). Applications of the Session Rating of Perceived Exertion System in Professional Rugby Union. *Strength & Conditioning Journal , 35* (6), 78–85.

Cormack, S., Newton, R., & McGuigan, M. (2008). Neuromuscular and endocrine responses of elite players to an Australian rules football match. *International Journal of Sports Physiology and Performance , 3*, 359–374.

Cormack, S., Newton, R., McGuigan, M., & Cormie, P. (2008). Neuromuscular and endocrine responses of elite players during an Australian rules football season. *Int J Sports Physiol Perform , 3* (4), 439-453.

Costill, D., Coyle, E., Fink, W., Lesmes, G., & Witzmann, F. (1979). Adaptations in skeletal muscle following strength training. *Journal of Applied Physiology , 46* (1), 96-99.

Coutts, A., & Duffield, R. (2010). Validity and reliability of GPS devices for measuring movement demands of team sports. *Journal of Science and Medicine in Sport , 13* (1), 133-135.

Coutts, A., Rampinini, E., Marcora, S. M., Castagna, C., & Impellizzeri, F. M. (2009). Heart rate and blood lactate correlates of perceived exertion during small-sided soccer games. *Journal of Science and Medicine in Sport Science , 12* (1), 79–84.

Coutts, A., Reaburn, P., Murphy, A., Pine, M., & Impellizzeri, F. (2003). Validity of the session-RPE method for determining training load in team sport athletes. *Journal of Science and Medicine in Sport , 6* (4), 525.

Coutts, A., Slattery, K., & Wallace, L. (2007). Practical tests for monitoring performance, fatigue and recovery in triathletes. *Journal of Science and Medicine in Sport , 10* (6), 372-381.

Crewther, B., Cook, C., Gaviglio, C., Kilduff, L., & Drawer, S. (2012). Baseline strength can influence the ability of salivary free testosterone to predict squat and sprinting performance. *J Strength Cond Res , 26* (1), 261-268.

Crewther, B., Kilduff, L., Cunningham, D., Cook, C., Owen, N., & Yang, G.-Z. (2011). Validating two systems for estimating force and power. *International Journal of Sports Medicine , 32*, 254–258.

Cronin, J., McNair, P., & Marshall, R. (2003). Lunge performance and its determinants. *Journal of sports sciences , 21* (1), 49-57.

Cummins, C., Orr, R., O'Conor, H., & West, C. (2013). Global positioning systems (GPS) and microtechnology sensors in team sports: a systematic review. *Sports Med , 43*, 1025-1042.

Cunniffe, B., Proctor, W., Baker, J., & Davies, B. (2009). An evaluation of the physiological demands of elite rugby union using global positioning system tracking software. *The Journal of Strength & Conditioning Research , 23* (4), 1195-1203.

Curren, S., Andrykowski, M., & Studts, J. (1995). Short form of the Profile of Mood States (POMS-SF): Psychometric information. *Psychological Assessment , 7*, 80- 83.

Da Silva, J., Guglielmo, L., & Bishop, D. (2010). Relationship between different measures of aerobic fitness and repeated sprint ability in elite soccer players. *Journal of Strength and Conditioning Research , 24* (8), 2115–2121.

Da Silva, J., Guglielmo, L., & Bishop, D. (2010). Relationship between different measures of aerobic fitness and repeated sprint ability in elite soccer players. *J Strength Cond Res , 24* (8), 2115-2121.

Dawson, B., Goodman, C., Lawrence, S., Preen, D., Polglaze, T., Fitzsimons, M., et al. (1997). Muscle phosphocreatine repletion following single and repeated short sprint efforts. *Scandinavian Journal of Medicine & Science in Sports , 7*, 206-213.

Day, M., McGuigan, M., Brice, G., & Foster, C. (2004). Monitoring Exercise Intensity During Resistance Training Using the Session RPE Scale. *Journal of Strength and Conditioning Research , 18* (2), 353–358.

de Oliveira, V., Bessa, A., & Lamounier, R. (2010). Changes in the salivary biomarkers induced by an effort test. *Int J Sports Med , 31* (6), 377-8.

DeCaro, J. (2008). Methodological considerations in the use of salivary alpha-amylase as a stress marker in field research. *Am. J. Hum. Biol , 20* (5), 617-619.

Dimitriou, L., Sharp, N., & Doherty, M. (2002). Circadian effects on the acute responses of salivary cortisol and IgA in well trained swimmers. *British journal of sports medicine , 36* (4), 260-264.

Drust, B., Reilly, T., & Cable, N. (2000). Physiological responses to laboratory-based soccer-specific intermittent and continuous exercise. *Journal of Sports Science , 18*, 885–892.

Edge, J., Bishop, D., & Goodman, C. (2006). The effects of training intensity on muscle buffer capacity in females. *European Journal of Applied Physiology , 96* (1), 97-105.

Edwards, S. (1993). High performance training and racing. In S. Edwards (Ed.), *The Heart Rate Monitor Book* (pp. 113-123). Sacramento: Feet Fleet Press.

Eichner, E. (1995). Overtraining: Consequences and prevention. *Journal of Sports Sciences , 13*, S41-S48.

Elliott, M., Wagner, P., & Chiu, L. (2008). Power athletes and distance training. Physiological and biomechanical rationale for change. *Sports Medicine , 37* (1), 47-57.

Elloumi, M., Makni, E., Moalla, W., Bouaziz, T., Tabka, Z., Lac, G., et al. (2012). Monitoring training load and fatigue in rugby sevens players. *Asian journal of sports medicine , 3* (3), 175.

Elloumi, M., Makni,, E., Moalla, W., Bouaziz, T., Tabka, Z., & Chamari, K. (2012). Monitoring Training Load and Fatigue in Rugby Sevens Players. *Asian Journal of Sports Medicine , 3* (3), 175-184.

Elloumi, M., Maso, F., Michaux, O., Robert, A., & Lac, G. (2003). Behaviour of saliva cortisol [C], testosterone [T] and the T/C ratio during a rugby match and during the post-competition recovery days. *European journal of applied physiology , 90* (1), 23-28.

Enoka, R. (2008). *Neuromechanics of human movement* (Vol. 4). Champaign, IL, USA: Human Kinetics.

Eston, R., & Reilly, T. (2009). *Kinanthropometry and exercise physiology laboratory manual. Tests, procedures and data* (Vol. 3). Oxon, UK: Routledge.

Evangelista, N. (1996). *The art and science of fencing.* Chicago, Illinois: McGraw-Hill Contemporary.

Fahlman, M., & Engels, H. (2005). Mucosal IgA and URTI in American college football players: a year longitudinal study. *Med Sci Sports Exerc. , 37* (3), 374-80.

Fazackerley, R., Lane, A., & Mahoney, C. (2003). Confirmatory factor analysis of the Brunel Mood Scale for use with water- skiing competition. *Perceptual and Motor Skills , 97*, 657-661.

FIE. (2014, September 1). *International Fencing Federation*. Retrieved June 1, 2014, from International Fencing Federation: http://fie.org/fie/documents/rules

Field, A. (2013). *Discovering Statistics using IBM SPSS Statistics* (Vol. 4). London: Sage.

Filaire, E., Bernain, X., Sagnol, M., & Lac, G. (2001). Preliminary Results on Mood State, Salivary Testosterone: Cortisol Ratio and Team Performance in a Professional Soccer Team. *European Journal of Applied Physiology & Occupational Physiology , 86* (2), 179-184.

Flanagan, E., & Comyns, T. (2008). The Use of Contact Time and the Reactive Strength Index to Optimize Fast Stretch-Shortening Cycle Training. *Strength & Conditioning Journal , 30* (5), 32-38.

Foster, C. (1998). Monitoring Training in Athletes with Reference to Overtraining Syndrome. *Medicine and Science in Sports and Exercise , 30* (7), 1164–1168.

Foster, C., Daines, E., Hector, L., Snyder, A. C., & Welsh, R. (1996). Athletic Performance in Relation to Training Load. *Wisconsin Medical Journal , 95* (6), 370-374.

Foster, C., Florhaug, J., Franklin, J., Gottschall, L., Hrovatin, L., Parker, S., et al. (2001). A New Approach to Monitoring Exercise Training. *Journal of Strength and Conditioning Research , 15* (1), 109-115.

Foster, C., Hector, R., Welsh, M., Schrager, M., Green, M. A., & Snyder, A. C. (1995). Effects of specific versus cross-training on running performance. *European Journal of Applied Physiology , 70* (4), 367-372.

Foster, C., Helmann, K., Esten, P., Brice, G., & Porcari, J. (2001). Differences in perceptions of training by coaches and athletes. *South African Sports Medicine Association , 8*, 3-7.

French, D., Kraemer, W., Volek, J., Spiering, B., Judelson, D., Hoffman, J., et al. (2007). Anticipatory response of catecholamine's on muscle force production. *J. Appl. Phsiol , 102*, 94-102.

Frere, J., Gopfert, B., & Nuesh, C. (2011). Kinematical and EMG-Classifications of a Fencing Attack. *International Journal of Sports Medicine , 32* (1), 28-34.

Fry, A., Kraemer, W., & Ramsey, L. T. (1998). Pituitary-adrenal-gonadal responses to high-intensity resistance exercise overtraining. *Journal of Applied Physiology , 85*, 2352-2359.

Gabbett, T. (2004). Influence of training and match intensity on injuries in rugby league. *Journal of Sports Sciences , 222* (5), 409-417.

Gaitanos, G., Williams, C., Boobis, L., & Brooks, S. (1993). Human muscle metabolism during intermittent maximal exercise. *J Appl Physiol , 75* (2), 712-719.

Garrett, J. (1987). The proper role of nerves in salivary secretion: a review. *J. Dent. Res , 66* (2), 387—397.

Gholipour, M., Tabrizi, A., & Farahmand, F. (2008). Kinematics Analysis of Lunge Fencing Using Stereophotogrametry. *World Journal of Sport Sciences , 1* (1), 32-37.

Gladwell, V., Sandercock, G., & Birch, S. (2010). Cardiac vagal activity following three intensities of exercise in humans. *Clinical Physiology and Functional Imaging , 30* (1), 17-22.

Glaister, M. (2005). Multiple sprint work: Physiological responses, mechanisms of fatigue and the influence of aerobic fitness. *Sports Med , 35*, 757-777.

Glaister, M., Stone, M., Stewart, A., Hughes, M., & Moir, G. (2005). The influence of recovery duration on multiple sprint cycling performance. *J Strength Cond Res , 19*, 831-837.

Gleeson, M., McDonald, W., & Pyne, D. (2000). Immune status and respiratory illness for elite swimmers during a 12-week training cycle. *Int J Sports Med , 21* (4), 302-7.

Gleeson, M., McDonald, W., & Pyne, D. (1999). Salivary IgA levels and infection risk in elite swimmers. *Med Sci Sports Exerc , 31* (1), 67-73.

Granger, D., Kivlighan, K., Blair, C., El-Sheikh, M., Mize, J., Lisonbee, J., et al. (2006). Integrating the measurement of salivary alpha-amylase into studies of child health, development, and social relationships. *J. Pers. Soc. Relat , 23*, 267—290.

Granger, D., Schwartz, E., Booth, A., & Arentz, M. (1999). Salivary testosterone determination in studies of child health and development. *Hormones and Behavior , 35*, 18-27.

Granger, D., Shirtcliff, E., Booth, A., Kivlighan, K., & Schwartz, E. (2004). The "trouble" with salivary testosterone. *Psychoneuroendocrinology , 29* (10), 1229-1240.

Greenhalgh, A., Bottoms, L., & Sinclair, J. (2013). Influence of Surface on Impact Shock Experienced during a Fencing Lunge. *J Appl Biomech , 29* (4), 463-467.

Gresham-Fiegel, C., House, P., & Zupan, M. (2013). The effect of nonleading foot placement on power and velocity in the fencing lunge. *The Journal of Strength & Conditioning Research , 27* (1), 57-63.

Groschl, M., Kohler, H., Topf, H. R., & Rauh, M. (2008). Evaluation of saliva collection devices for the analysis of steroids, peptides and therapeutic drugs. *Journal of Pharmaceutical and Biomedical Analysis , 47*, 478–486.

Grove, J. R., & Prappavessis, H. (1992). Preliminary evidence for the reliability and validity of an abbreviated Profile of Mood State questionnaire. *International Journal of Sport Psychology , 23*, 93-109.

Guilhem, G., Giroux, C. C., Chollet, D., & Rabita, G. (2014). Mechanical and Muscular Coordination Patterns during a High-Level Fencing Assault . *Medicine and science in sports and exercise , 46* (2), 341-50.

Gutierrez-Davila, M. (2011). Response timing in the lunge and target change in elite versus medium-level fencers. *European Journal of Sport Science* , 1-8.

Gutmann, M., Pollock, M., Foster, C., & Schmidt, D. (1984). Training stress in Olympic speed skaters: A psychological perspective. *Physician and Sportsmedicine , 12*, 45-47.

Haddad, M., Chaouachi, A., Castagna, C., Wong, P. L., Behm, D. G., & Chamari, K. (2011). The construct validity of session RPE during an intensive camp in young male Taekwondo athletes. *International Journal of Physiology and Performance , 6*, 252-263.

Haff, G., Carlock, J., & Hartman, M. (2005). Force–time curve char- acteristics of dynamic and isometric muscle actions of elite women Olympic weightlifters. *J Strength Cond Res , 19* (4), 741-748.

Halson, S., Bridge, M., Meeusen, R., Busschaert, B., Gleeson, M., & Jones, D. (2002). Time course of performance changes and fatigue markers during intensified training in trained cyclists. *Journal of Applied Physiology , 93*, 947-956.

Harmer, P. (2008). Incidence and Characteristics of time-loss injuries in competitive fencing: A prospective, 5-year study of national competitions. *Clinical Journal of Sports Medicine , 18* (2), 137-142.

Harris, R., Edward, R., Hultman, E., Nordesjo, L., Nylind, B., & Sahlin, K. (1976). The time course of phosphorylcreatine resynthesis during recovery of the quadricepts muscle in man. *Pflügers Archiv European Journal of Physiology , 367*, 137-142.

Hashim, H., Zulkifli, E., & Ahmad, H. (2010). Factorial validation of Malaysian adapted Brunel Mood Scale in an adolescent sample. *Asian Journal of Sports Medicine , 1*, 185-194.

Helgerud, J., Hoydal, K., Wang, E., Karlsen, T., Berg, P., & Bjerkaas, M. (2007). Aerobic high intensity intervals improve VO2max more than moderate training. *Medicine in Science and Sport and Exercise , 39*, 665-671.

Helgerud, J., Hoydal, K., Wang, E., Karlsen, T., Berg, P., & Bjerkaas, M. (2007). Aerobic highintensity intervals improve VO2max more than moderate training. *Medicine in Science and Sport and Exercise , 39*, 665-671.

Hirvonen, J., Rehunen, S., Rusko, H., & Härkönen, M. (1987). Breakdown of high-energy phosphate compounds and lactate accumulation during short supramaximal exercise. *European Journal of Applied Physiology and Occupational Physiology , 56* (3), 253-259.

Hoffman. (1997). The relationship between aerobic fitness and recovery from high-intensity exercise in infantry soldiers. *Military Medicine , 162*, 484-488.

Hoffman, J., Maresh, C., Newton, R., Rubin, M., French, D., Volek, J., et al. (2002). Performance, biochemical, and endocrine changes during a competitive football game. *Medicine and science in sports and exercise , 34* (11), 1845-53.

Hoffman, J., Tenenbaum, G., Maresh, C., & Kraemer, W. (1996). Relationship between athletic performance tests and playing time in elite college basketball players. *Journal of Strength and Conditioning Research , 10*, 67-71.

Hogan, M., Kohin, S., Stary, C., & Hepple, R. (1999). Rapid force recovery in contracting skeletal muscle after brief ischemia is dependent on O2 availability. *J Appl Physiol , 87* (6), 2225-2229.

Hooper, S., & Mackinnon, L. (1995). Monitoring Overtraining in Athletes: Recommendations. *Sports Medicine , 20*, 321–327.

Hopkins. (2004). How to interpret changes in an athletic performance test. *Sportscience , 8*, 1-7.

Hopkins, W. (2002). *A scale of magnitudes for effect statistics.* Retrieved from sportsci.org/resource/stats/index.html.

Hox, J. (2010). *Multilevel analysis: Techniques and applications.* Mahwah, NJ: Lawrence Erlbaum.

Hultman, E., & Sjöholm, H. (1983). Energy metabolism and contraction force of human skeletal muscle in situ during electrical stimulation. *J Physiol , 345*, 525-532.

Hultman, E., Bergstrom, J., & Anderson, N. (1967). Breakdown and resynthesis of phosphorylcreatine and adenosine triphosphate in connection with muscular work in man. *Scandinavian Journal of Clinical and Laboratory Investigation , 19*, 56-66.

Humphrey, S., & Williamson, R. (2001). A review of saliva: normal composition, flow, and function. *J. Prosthet. Dent , 85*, 162-169.

Impellizzeri, F., Rampinini, E., Coutts, A., Sassi, A., & Marcora, S. (2004). Use of RPE-Based Training Load in Soccer. *Medicine and Science in Sports and Exercise , 36* (6), 1042-1047.

Impellizzeri, F., Rampinni, M. M., & Marcora, S. (2007). A Vertical Jump Force Test for Assessing Bilateral Strength Asymmetry in Athletes. *Medicine and Science in Sports and Exercise , 39* (11), 2044-2050.

Impellizzeri, F., Rampinni, M., & Marcora, S. (2007). A vertical jump force test for assessing bilateral strength asymmetry in athletes. *Medicine and Science in Sports and Exercise , 39*, 2044-2050.

Jaric, S., Ropert, R., Kukolj, M., & Ilic, D. (1995). Role of agonist and antagonist muscle strength in rapid movement performance. *European Journal of Applied Physioliogy , 71*, 464 - 468.

Jensen, R., & Ebben, W. (2007). Quantifying plyometric intensity via rate of force development, knee joint, and ground reaction forces. *J. Strength C ond. Res , 21* (3), 763-767.

Johnson, C., & McHugh, M. (2006). Performance demands of professional male tennis players. *British Journal of Sports Medicine , 40*, 696-699.

Johnson, R., Gibson, N., Twist, C., Gabbett, T., MacNay, S., & MacFarlane, N. (2013). Physiological responses to an intensified period of rugby league competition. *The Journal of Strength & Conditioning Research , 27* (3), 643-654.

Johnston, R. D., Gabbett, T. J., Jenkins, D. G., & Julin, B. T. (2014). Influence of physical qualities on post-match fatigue in rugby league. *Journal of Science and Medicine in Sport* , 1-4.

Jones, N., McCartney, N., Graham, T., Spriet, L., Kowalchuk, J., Heigenhauser, G., et al. (1985). Muscle performance and metabolism in maximal isokinetic cycling at slow and fast speeds . *J Appl Physiol , 59*, 132-136.

Jurimae, J., Maestu, J., Purge, P., & Jurimae, T. (2004). Changes in stress and recovery after heavy training in rowers. *Journal of Science and Medicine in Sport , 7*, 334-339.

Kallus, D. W. (1995). *Der Erholungs-Belastungs- Fragebogen (The Recovery–Stress-Questionnaire)*. Frankfurt: Swets & Zeitlinger.

Kellmann, M. (2010). Preventing overtraining in athletes in high-intensity sports and stress/recovery monitoring. *Scandinavian journal of medicine and science in sports , Suppl 2* (Available at: http://www.ncbi.nlm.nih.gov/pubmed/20840567), 95-102.

Kellmann, M., & Gunther, K. D. (2000). Changes in stress and recovery in elite rowers during preparation for the Olympic games. *Medicine and Science in Sports and Exercise , 32*, 676-683.

Kellmann, M., & Kallus, K. W. (2001). *The Recovery– Stress Questionnaire for Athletes; user manual.* Champaign, IL: Human Kinetics.

Kenney, W., Wilmore, J., & Costill, D. (2011). *Physiology of Sport and Exercise* (5th Edition ed.). Illinois, USA: Human Kinetics.

Kenttä, G., & Hassmén, P. (1998). Overtraining and Recovery A Conceptual Model. *Sports Medicine , 26* (1), 1-16.

Kenttä, G., & Hassmén, P. (2002). Overtraining and Recovery A Conceptual Model. In K. Kellman (Ed.), *Enhancing recovery: Preventing underperformance in athletes* (pp. 57-59). Human Kinetics,.

Kivlighan, K., & Granger, D. (2006). Salivary α-amylase response to competition: Relation to gender, previous experience, and attitudes. *Psychoneuroendocrinology , 31* (6), 703-714.

Klein, L., Bennett, J., Whetzel, C., Granger, D., & Ritter, F. (2010). Caffeine and stress alter salivary α-amylase activity in young men. *Human Psychopharmacology: Clinical and Experimental , 25* (5), 359-367.

Koutedakis, Y., Ridgeon, A., Sharp, N., & Boreham, C. (1993). Seasonal variation of selected performance parameters in épée fencers. *British journal of sports medicine , 27* (3), 171-174.

Kraemer, French, D., Paxton, N., Hakkinen, K., Volek, J., Sebastianelli, W., et al. (2004). Changes in exercise performance and hormonal concentrations over a Big Ten soccer season in starters and nonstarters. *Journal of Strength and Conditioning Research , 18*, 121–128.

Kraemer, W. J., Fleck, S. J., Dziados, J. E., Harman, E., Marchitelli, L. J., Gordon, S. E., et al. (1993). Changes in hormonal concentrations following different heavy resistance exercise protocols in women. *Journal of Applied Physiology , 75*, 594-604.

Kraemer, W. J., French, D. N., Paxton, N. J., Häkkinen, K., Volek, J. S., Sebastianelli, W. J., et al. (2004). Changes in exercise performance and hormonal concerntrations over a big ten soccer season in starters and nonstarters. *Journal of Strength and Conditioning Research , 18* (1), 121-128.

Kraemer, W., Fry, A., Warren, B., Stone, M., Fleck, S., Kearney, J., et al. (1992). Acute hormonal responses in elite junior weightlifters. *International journal of sports medicine , 13* (02), 103-109.

Lambert, M., & Borresen, J. A. (2006). Theoretical Basis of Monitoring Fatigue: A Practical Approach for Coaches. *International Journal of Sports Science & Coaching , 1* (4), 449-457.

Lamberts, R., & Lambert, M. (2009). Day-to-day variation in heart rate at different levels of submaximal exertion: implications for monitoring training. *The Journal of Strength & Conditioning Research , 23* (3), 1005-1010.

Lamberts, R., Lemmink, K., Durandt, J., & Lambert, M. (2004). Variation in heart rate during submaximal exercise: implications for monitoring training. *J Strength Cond Res , 18*, 641-645.

Lamberts, R., Maskell, S., Borresen, J., & Lambert, M. (2011). Adapting workload improves the measurement of heart rate recovery. *International journal of sports medicine , 32* (9), 698.

Lamberts, R., Rietjens, G., Tijdink, H., Noakes, T., & Lambert, M. (2010). Measuring submaximal performance parameters to monitor fatigue and predict cycling performance: a case study of a world-class cyclo-cross cyclist. *Eur J Appl Physiol , 108*, 183-190.

Lamberts, R., Swart, J., Capostagno, B., Noakes, T., & Lambert, M. (2010). Heart rate recovery as a guide to monitor fatigue and predict changes in performance parameters. *Scandinavian Journal of Medicine & Science in Sports , 20* (3), 449-57.

Lan, M., Lane, A., Roy, J., & Hanin, N. (2012). Validity of the Brunel Mood Scale for use With Malaysian Athletes. *Journal of Sports Science & Medicine , 11* (1), 131-135.

Lane, A., Soos, I., Leibinger, E., Karsai, I., & Hamar, P. (2007). Validity of the Brunel Mood Scale for use with UK, Italian and Hungarian Athletes. In A. M. Lane (Ed.), *Mood and human performance: Conceptual, measurement, and applied issues* (pp. 119-130). Hauppauge, NY: Nova Science,.

Lane, A., Terry, P., Stevens, M., Barney, S., & Dinsdale, S. (2004). Mood responses to athletic performance in extreme environments. *Journal of sports sciences , 22* (10), 886-897.

Lebanthal, E. (1987). Role of salivary amylase in gastric and intestinal digestion of starch. *Digestion, Diseases, Sci , 32*, 1155–1157.

Li, J., Wang, X., Fraser, S., Carey, M., Wrigley, T., & McKenna, M. J. (2002). Effects of Fatigue and Training on Sarcoplasmic Reticulum Ca(2+) Regulationin Human Skeletal Muscle. *Journal of Applied Physiology , 92*, 912-922.

Libicz, S., Mercier, B., Bigou, N., Le Gallais, D., & Castex, F. (2006). Salivary IgA response of triathletes participating in the French Iron Tour. *Int J Sports Med , 27* (5), 389-94.

Linnamo, V., Newton, R. U., Hakkinen, K., Komi, P. V., Davie, A., McGuigan, M., et al. (2000). Neuromuscular Response to Explosive and Heavy Resistance Loading. *Journal of Electromyography & Kinesiology , 10* (6), 417-424.

Linnamo, V., Pakarinen, A., Komi, P., Kraemer, W., & Häkkinen, K. (2005). Acute hormonal responses to submaximal and maximal heavy resistance and explosive exercises in men and women. *The Journal of Strength & Conditioning Research , 19* (3), 566-571.

Linthorne, N. (2011). Analysis of standing vertical jumps using a force platform. *American Journal of Physics , 69* (11), 1198-1204.

Ljungberg, G., Ericson, T., Ekblom, B., & Birkhed, D. (1997). Saliva and marathon running. *Scand. J. Med. Sci. Sports , 7*, 214-219.

Lopes, P., & White, J. (2006). Heart rate Variability: Measurement Methods and Practical Implications. In P. J. Maud, & C. Foster (Eds.), *Physiological Assessment of Human Fitness* (pp. 39-61). USA: Human Kinetics.

Lu, S., Lau, C., Tung, Y., Huang, S., Chen, Y., Shih, H., et al. (1997). Lactate and the effects of exercise on testosterone secretion: evidence for the involvement of a cAMP-mediated mechanism. *Medicine and science in sports and exercise , 29* (8), 1048-1054.

MacFarlane, N., Northridge, D., Wright, A. G., & Dargie, H. (1991). A comparative study of left ventricular structure and function in elite athletes. *British journal of sports medicine , 25* (1), 45-48.

Mackinnon, L., & Hooper, S. (1994). Mucosal (secretory) immune system responses to exercise of varying intensity and during overtraining. *Int J Sports Med , 15*, S179-183.

Mackinnon, L., Ginn, E., & Seymour, G. (1993). Decreased salivary immunoglobulin A secretion rate after intense interval exercise in elite kayakers. *Eur J Appl Physiol Occup Physiol , 67* (2), 180-4.

Maestu, J., Jurimae, J., Kreegipou, K., & Jurimae, T. (2006). Changes in perceived stress and recovery during heavy training in highly trained rowers. *Sport Psychology , 20*, 24-39.

Manzi, V., D'Ottavio, S., Impellizzeri, F. M., Chaouachi, A., Chamari, K., & Castagna, C. (2010). Profile of weekly training load in elite male professional basketball players. *The Journal of Strength & Conditioning Research , 24* (5), 399-1406.

Markovic, G., Dizadar, D., Jukic, I., & Cardinale, M. (2004). Reliability and factorial validity of squat and countermovement jump tests. *Journal of Strength and Conditioning Research , 18* (3), 551-553.

Mazanec, M., Nedrud, J., & Kaetzel, C. (1993). A three-tiered viewof the role of IgA in mucosal defense. *Immunol Today , 14* (9), 430-5.

McGuigan, M., & Cormack, S. (2011). Biochemical monitoring in strength and conditioning. In M. Cardinale, R. Newton, & K. Nosaka (Eds.), *Strength and Conditioning. Biological principles and practical applications* (pp. 179-188). UK: Wiley-Blackwell.

McGuigan, M., Egan, A., & Foster, C. (2004). Salivary Cortisol Responses and Perceived Exertion During High Intensity and Low Intensity Bouts of Resistance Exercise. *Journal of Sports Science and Medicine , 3* (1), 8-15.

McHugh, M. (2003). Recent advances in the understanding of the repeated bout effect: The protective effect against muscle damage from a single bout of eccentric exercise. *Scandanavian Journal of Medicine and Science in Sports , 13*, 88-97.

Mclellan, C., & Lovell, D. (2010). reatine Kinase and Endocrine Responses of Elite Player Pre, During, and Post Rugby League Match Play. *The Journal of Strength & Conditioning Research , 24* (11), 2908–2919.

McNair, D., Lorr, M., & Droppleman, L. (1971). *Manual for the Profile of Mood States, Educational and Industrial Testing Service.* San Diego, CA.

Meeusen, R. (2014). Exercise, Nutrition and the Brain. *Sports Medicine , 44* (1), S47–S56.

Meeusen, R., Duclos, M., Foster, C., Fry, A., Glesson, M., Nieman, D., et al. (2013). Prevention, diagnosis, and treatment of the overtraining syndrome: joint consensus statement of the European College of Sport Science and the American College of Sports Medicine. *Medicine and science in sports and exercise , 45* (1), 186-205.

Meeusen, R., Gleeson, M., Rietjens, M., & Steinacker, G. (2006). Prevention, diagnosis and treatment of the Overtraining Syndrome. *European Journal of Sport Science , 6* (1), 1-14.

Meeusen, R., Piacentini, M., & Busschaert, B. (2004). Hormonal responses in athletes: the use of a two bout exercise protocol to detect subtle dif- ferences in (over)training status. *Eur J Appl Physiol , 91*, 140-6.

Milia, R., Roberto, S., Palazzolo, G., Sanna, I., Omeri, M., Piredda, S., et al. (2014). Physiological responses and energy expenditure during competitive fencing. *Applied physiology, nutrition, and metabolism , 39* (3), 324–8.

Mirwald, R. B.-J., & Bailey, D. (2002). An assessment of maturity from anthropometric measurements. *Medicine & Science in Sports & Exercise , 34* (4), 689-694.

Miyama, M., & Nosaka, K. (2004). Influence of surface on muscle damage and soreness induced by consecutive drop jumps. *Journal of Strength and Conditioning Research , 18* (2), 206–211.

Miyama, M., & Nosaka, K. (2004). Muscle damage and soreness following repeated bouts of consecutive drop jumps. *Advanced Exercise in Sports Physiology , 10*, 63-69.

Mooney, M., Cormack, S., O'Brien, B., Morgan, W., & McGuigan, M. (2013). Impact of neuromuscular fatigue on match exercise intensity and performance in elite Australian football. *Journal of Strength and Conditioning Research , 27* (1), 166-173.

Moreira, A., Arsati, F., & Lima-Arsati, Y. (2010). Effect of a kickboxing match on salivary cortisol and immunoglobulin A. *Percept Mot Skills , 111* (1), 158-66.

Morgan, W., Brown, D., Raglin, J., O'Connor, P., & Ellickson, A. (1987). Psychological monitoring of overtraining and staleness. *British Journal of Sports Medicine , 21* (3), 107-114.

Mujika, I., Padilla, S., Adilla, S., Ibanez, J., Izquierdo, I., & Gorostiaga, E. (2000). Creatine supplementation and sprint performance in soccer players. *Med. Sci. Sports Exerc , 32* (2), 2000.

Nakamaru, Y., & Schwartz, A. (1972). The Influence of Hydrogen Ion Concentration on Calcium Binding and Release by Skeletal Muscle Sarcoplasmic Reticulum. *J Gen Physiol , 59*, 22-32.

Nater, U., & Rohleder, N. (2009). Salivary alpha-amylase as a non-invasive biomarker for the sympathetic nervous system: current state of research . *Psychoneuroendocrinology , 34* (4), 486496.

Nater, U., La Marca, R., Florin, L., Moses, A., Langhans, W., Koller, M., et al. (2006). Stress-induced changes in human salivary alpha-amylase activity—associations with adrenergic activity. *Psychoneuroendocrinology , 31* (1), 49-58.

Nater, U., Rohleder, N., Gaab, J., Berger, S., Jud, A., Kirschbaum, C., et al. (2005). Human salivary alpha-amylase reactivity in a psychosocial stress paradigm. *Int. J. Psychophysiol , 55*, 333-342.

Navazesh, M. (1993). Methods for collecting saliva. *Ann. NYAcad. Sci , 694*, 72-77.

Navazesh, M., & Kumar, S. (2008). Measuring salivary flow: challenges and opportunities. *J. Am. Dent. Assoc , 139*, 35S-40S.

Neville, V., Gleeson, M., & Folland, J. P. (2008). Salivary IgA as a Risk Factor for Upper Respiratory Infections in Elite Professional Athletes. *Medicine & Science in Sports & Exercise , 40* (7), 1228–1236.

Newton, M., Morgan, G., Sacco, P., Chapman, D., & Nosaka, K. (2008). Comparison of Responses to Strenuous Eccentric Exercise of the Elbow Flexors Between Resistance-Trained and Untrained Men . *Journal of Strength & Conditioning Research , 22* (2), 597-607.

Nexo, E., Hansen, M., & Konradsen, L. (1988). Human salivary epi- dermal growth factor, haptocorrin and amylase before and after prolonged exercise. *Scand. J. Clin. Lab. Invest , 48*, 269—273.

Nguyen, D., Brown, L., Coburn, J., Judelson, D., Eurich, A., Khamoui, A., et al. (2009). Effect of delayed-onset muscle soreness on elbow flexion strength and rate of velocity development. *The Journal of Strength & Conditioning Research , 23* (4), 1282-1286.

Nieman, D. (1994). Exercise, infection and immunity. *Int J Sports Med , 15*, S131–S141.

Nigg, & Segesser, B. (1992). Biomechanical and orthopedic concepts in sport shoe construction. *Medicine and Science in Sports Exercise , 24* (5), 595-602.

Nosake, K. (2011). Exercise-induced muscle damage and delayed-onset muscle soreness (DOMS). In M. Cardinale, R. Newton, & K. Nosaka (Eds.), *Strength and Conditioning. Biological principles and practical applications* (pp. 179-188). UK: Wiley-Blackwell.

Novas, A., Rowbottom, D., & Jenkins, D. (2003). Tennis, incidence of URTI and salivary IgA. . *Int J Sports Med , 24* (3), 223-9.

O'Donoghue. (2012). *Statistics for sport and exercise studies. An introduction.* London, UK: Routledge.

Oliver. (2009). Is a fatigue index a worthwhile measure of repeated sprint ability? *J. Sci. Med. Sport , 12*, 20-23.

Oliver, G., & Keeley, D. (2010). Pelvis and torso kinematics and their relationship to shoulder kinematics in high-school baseball pitchers. *Journal of Strength and Conditioning Research , 24*, 3241-3246.

Osgnach, C., Poser, S., Bernardini, R., Rinaldi, R., & Di Prampero, P. E. (2010). Energy cost and metabolic power in elite soccer: a new match analysis approach. *Medicine and science in sports and exercise , 42* (1), 170-178.

Owen, N., Watkins, L., Kilduff, L., Bevan, H., & Bennett, M. (2004). Development of a criterion method to determine peak mechanical power output in a countermovement jump. *Journal of strength and conditioning research , 28*, 1552–8.

Padilla, S., Mujika, J., Orbananos, J., & Angulo, F. (2000). Exercise intensity during competition time trials in professional road cycling. *Medicine and Science in Sports and Exercise , 32*, 850-856.

Padilla, S., Mujika, J., Orbananos, J., Santisteban, J., Angulo, F., & Goiriena, J. (2001). Exercise intensity and load during mass- start stage races in professional road cycling. *Medicine and Science in Sports and Exercise , 33*, 796–802.

Papacosta, E., & Nassis, G. (2011). Saliva as a tool for monitoring steroid, peptide and immune markers in sport and exercise science. *Journal of Science and Medicine in Sport , 14* (5), 424-434.

Parolin, M., Chesley, A., Matsos, M., Spriet, L., Jones, N., & Heigenhauser, G. (1999). Regulation of skeletal muscle glycogen phosphorylase and PDH during maximal intermittent exercise. *Am J Physiol Endocrinol Metab , 277* (5), E890-E900.

Peterson, M., Alvar, B., & Rhea, M. (2006). The contribution of maximal force production to explosive movement among young collegiate athletes. *Journal of Strength and Conditioning Research , 20* (4), 867-873.

Pichot, V., Roche, F., Gaspoz, J. M., Enjolras, F., Antoniadis, A., Minini, P., et al. (2000). Relation between heart rate variability and training load in middle-distance runners. *Medicine & Science in Sports & Exercise , 32* (10), 1729 - 1736.

Pilegaard, H., Domino, K., Noland, T., & Bangsbo, J. (1999). Effect of high-intensity exercise training on lactate/H+ transport capacity in human skeletal muscle. *The American journal of physiology , 276*, E255-E261.

Pino, J., Martinez-Santos, R., Moreno, M., & Padilla, C. (2007). Automatic analysis of football games using GPS on real time. *J Sports Sci Med , 6*, 9.

Plews, D., Laursen, P., Kilding, A., & Buchheit, M. (2013). Evaluating Training Adaptation with Heart Rate Measures: A Methodological Comparison. *International Journal of Sports Physiology and Performance* .

Plews, D., Laursen, P., Kilding, A., & Buchheit, M. (2012). Heart rate variability in elite triathletes, is variation in variability the key to effective training? A case comparison. *Eur J Appl Physiol* .

Plisk, S., & Stone, M. (2003). Periodisation strategies. *Strength and Conditioning Journal , 25*, 19-37.

Pluim, B., Zwinderman, A., van der Laarse, A., & van der Wall, E. (2000). The athlete's heart a meta-analysis of cardiac structure and function. *Circulation , 101* (3), 336-344.

Pohl, M., Mullineaux, D., Milner, C., Hamill, J., & Davis, I. (2008). Biomechanical predictors of retrospective tibial stress fractures in runners. *Journal of Biomechanics , 41* (6), 1160-1165.

Port, K. (1991). Serum and saliva cortisol responses and blood lactate accu- mulation during incremental exercise testing. *Int J Sports Med , 12* (5), 490-4.

Proctor, G., & Carpenter, G. (2007). Regulation of salivary gland function by autonomic nerves. *Autonomic Neuroscience , 133* (1), 3-18.

Pyne, D. S., Montgomery, P., Hewitt, A., & Sheehan, K. (2008). Relationships between repeated sprint testing, speed, and endurance. *Journal of Strength and Conditioning Research , 22* (5), 1633– 1637.

Pyne, D., & Gleeson, M. (1998). Effects of intensive exercise training on immunity in athletes. *Int J Sports Med , 19* (3), 183-91.

Pyne, D., Saunders, P., Montgomery, P., Hewitt, A., & Sheehan, K. (2008). Relationships between repeated sprint testing, speed, and endurance. *J Strength Cond Res , 22* (5), 1633-1637.

Raastad, Owe, S., Paulsen, G., Enns, D., Overgaard, K., Cramer, R., et al. (2010). Changes in Calpain Activity, Muscle Structure, and Function after Eccentric Exercise. *Medicine and Science in Sports & Exercise , 42* (1), 86-95.

Raastad, Owe, S., Paulsen, G., Enns, D., Overgaard, K., Crameri, R., et al. (2010). Changes in Calpain Activity, Muscle Structure, and Function after Eccentric Exercise. *Medicine & Science in Sports & Exercise , 42* (1), 86-95.

Raglin, J., & Morgan, W. (1994). Development of a scale for use in monitoring training-induced distress in athletes. *International Journal of Sports Medicine , 15*, 84-88.

Raglin, J., Morgan, W., & Luchsinger, A. (1990). Mood and self-motivation in successful and unsuccessful female rowers. *Medicine and Science in Sports and Exercise , 22*, 849-853.

Rasbash, J., Steele, F., Browne, W., & Prosser, B. (2005). *A user's guide to MLwiN (Version 2.0).* Bristol, United Kingdom: University of Bristol.

Ratamess, N., Kraemer, W., Volek, J., Maresh, C., VanHeest, J., Sharman, M., et al. (2005). Androgen receptor content following heavy resistance exercise in men. *The Journal of steroid biochemistry and molecular biology , 93* (1), 35-42.

Ratmess, N. (2008). Adaptations to anaerobic training programs. In T. Baechle, & R. Earle, *Essentials of Strength Training and Conditioning* (pp. 93-119). Champaign, IL, USA: Human Kinetics.

Redondo, J., Alonso, C., Sedano, S., & de Benito, A. (In press). Effects of a 12-week strength training program on experimented fencers´ movement time. *Journal of Strength and Conditioning Research* .

Rhea, A. (2004). Determining the magnitude of treatment effects in strength training research through the use of the effect size statistic. *Journal of Strength and Conditioning Reserach , 18*, 918-920.

Rietjens, G., Kuipers, H., Adam, J., Saris, W., Van Breda, E., & Van Hamont, D. (2005). Physiological, biochemical and psychological markers of strenuous training- induced fatigue. *International Journal of Sports Medicine , 26*, 16-26.

Robertson, R., & Noble, B. (1997). Perceptions of physical exertion: Methods, mediators, and applications. In J. Holloszy, *Exercise and sport sciences reviews* (Vol. 25, pp. 407-452). Philadelphia: Williams and Wilkins.

Robson-Ansley, P. J., Blannin, A., & Gleeson, M. (2007). Elevated plasma interleukin-6 levels in trained male triathletes following an acute period of intense interval training. *European Journal of Applied Physiology , 99*, 353-360.

Robson-Ansley, P. J., Gleeson, M., & Ansley, L. (2009). Fatigue management in the preparation of Olympic athletes. *Journal of Sports Sciences , 27* (3), 1409–1420.

Rohleder, N., Wolf, J., Maldonado, E., & Kirschbaum, C. (2006). The psychosocial stress-induced increase in salivary alpha-amylase is independent of saliva flow rate. *Psychophysiology , 43* (6), 645-652.

Roi, G., & Bianchedi, D. (2008). The Science of Fencing. Implications for performance and injury prevention. *Sports Medicine , 38* (6), 465-481.

Roi, G., & Pittaluga, I. (1997). Time-motion analysis in women's sword fencing. *Proceedings of the fourth IOC Congress on Sport Sciences*, *66*, pp. 22-25. Monaco.

Rushall, B. S. (1990). A tool for measuring stress tolerance in elite athletes. *Journal of Applied Sports Psychology , 2*, 51-66.

Sahlin, K., & Henriksson, J. (1984). Buffer capacity and lactate accumulation in skeletal muscle of trained and untrained men. *Acta Physiol Scand , 122*, 331-339.

Sahlin, K., & Ren, J. (1989). Relationship of contraction capacity to metabolic changes during recovery from a fatiguing contraction. *J Appl Physiol , 67* (2), 648-654.

Saltin, B. (1973). Metabolic fundamentals in exercise. *Med Sci Sports , 5*, 137-146.

Sant'Ana Pereira, J., Sargeant, A., Rademaker, A., de Haan, A., & van Mechelen, W. (1996). Myosin heavy chain isoform expression and high energy phosphate content in human muscle fibres at rest and post-exercise. *J Physiol , 496* (2), 583-588.

Sant'Ana Pereira, J., Sargeant, A., Rademaker, A., de Haan, A., & Van Mechelen, W. (1996). Myosin heavy chain isoform expression and high energy phosphate content in human muscle fibres at rest and post-exercise. *Journal of Physiology , 496* (2), 583-588.

Sargeant, A., & Dolan, P. (1987). Effect of prior exercise on maximal short-term power output in humans . *J Appl Physiol , 63* (4), 1475-1480.

Selye, H. (1956). *The stress of life.* New York, USA: McGraw-Hill.

Shacham, S. (1983). shortened version of the Profile of Mood States. *Journal of Personality Assessment , 47*, 305-306.

Short, K., & Sedlock, D. (1997). Excess postexercise oxygen consumption and recovery rate in trained and untrained subjects. *J Appl Physiol , 83*, 153-159.

Signorile, J., Tremblay, L., & Ingalls, C. (1993). The Effects of Active and Passive Recovery on Short-Term, High Intensity Power Output. *Can J Appl Physiol , 18* (1), 31-42.

Skosnik, P., Chatterton, R., Swisher, T., & Park, S. (2000). Modulation of attentional inhibition by norepinephrine and cortisol after psychological stress. *Int. J. Psychophysiol , 36*, 59-68.

Spencer, M., Bishop, D., Dawson, B., & Goodman, C. (2005). Physiological and metabolic responses of repeated-sprint activities. *Sport Med , 35*, 1025-1044.

Spencer, M., Fitzsimons, M., & Dawson, B. (2006). Reliability of a repeated sprint test for field-hockey. *J Sci Med Sport , 9*, 181-184.

Stagno, K., Thatcher, R., & Van Someren, K. (2007). A modified TRIMP to quantify the in-season training load of team sport players. *Journal of Sports Sciences , 25*, 629-634.

Steerenberg, P., van Asperen, I., Van Nieuw Amerongen, A., Biewenga, J., Mol, D., & Medema, G. (1997). Salivary levels of immunoglobulin A in triathletes. *Eur. J. Oral Sci , 105*, 305—309.

Steinacker, J. M., Lormes, W., Kellmann, M., Liu, Y., Reibnecker, S., Opitz-Gress, A., et al. (2000). Training of junior rowers before World Championships. Effects on performance, mood State and selected hormonal and metabolic responses. *Journal of Sports Medicine and Physical Fitness , 40*, 327–335.

Steinacker, J., Kellmann, M., Bohm, B., Liu, Y., Opitz-Gress, A., Kallus, K., et al. (1999). Clinical findings and parameters of stress and regeneration in rowers before World Championships. In M. Lehmann, C. Foster, U. Gastmann, & J. M. Steinacker (Eds.), *Overload, fatigue, performance incompetence, and regeneration in sport* (pp. 71-80). New York: Plenum.

Stewart, S., & Kopetka, B. (2005). The kinematic determinants of speed in the fencing lunge. *Journal of Sports Sciences , 23* (2), 105.

Stone, M., O'Bryant, H., Schilling, B., Johnson, R., Pierce, K., Haff, G., et al. (1999). Periodization. Part 2: Effects of manipulating volume and intensity. *Strength and Conditioning Journal , 21*, 54–60.

Strazdins, L., Meyerkort, S., Brent, V., D'Souza, R., Broom, D., & Kyd, J. (2005). Impact of saliva collection methods on sIgA and cortisol assays and acceptability to participants. *J. Immunol. Methods , 307* (1), 167-171.

Sweet, T., Foster, C., McGuigan, M., & Brice, G. (2004). Quantification of Resistance Training Using the Session Rating of Perceived Exertion Method. *Journal of Strength and Conditioning Research , 18* (4), 796-802.

Terry, Lane, A., Lane, H., & Keohane, L. (1999). Development and validation of a mood measure for adolescents. *Journal of Sports Sciences , 17*, 861-872.

Terry, P., & Lane, A. (2010). *User guide to Brunel Mood Scale.* University of Southern Queensland.

Terry, P., Dinsdale, S., Karageorghis, C., & Lane, A. (2006). *Use and perceived effectiveness of pre-competition mood regulation strategies among athletes.* Retrieved from http://bura.brunel.ac.uk/handle/2438/1052

Terry, P., Lane, A., & Fogarty, G. (2003). Construct validity of the Profile of Mood States - Adolescents for use with adults. *Psychology of Sport and Exercise , 4*, 125-139.

Thebault, N., Leger, L., & Passelergue, P. (2011). Repeated-sprint ability and aerobic fitness. *J Strength Cond Res , 25* (10), 2857-2865.

Thomas, C., Sirvent, P., Perrey, S., Raynaud, E., & Mercier, J. (2004). Relationships between maximal muscle oxidative capacity and blood lactate removal after supramaximal exercise and fatigue indexes in humans. *J Appl Physiol , 97*, 2132-2138.

Tobias, G., Tobias, G., Benatti, F., de Salles Painelli, V., Roschel, H., Gualano, B., et al. (2013). Additive effects of beta-alanine and sodium bicarbonate on upper-body intermittent performance. *Amino Acids , 45* (2), 309-317.

Tomasi, T., Trudeau, F., Czerwinski, D., & Erredge, S. (1982). Immune parameters in athletes before and after strenuous exercise. *J Clin Immunol , 2* (3), 173-8.

Trautmann, C., Martinelli, N., & Rosenbaum, D. (2011). Foot loading characteristics during three fencing-specific movements. *Journal of sports sciences , 29* (15), 1585-92.

Trautmann, C., Martinelli, N., & Rosenbaum, D. (2011). Foot loading characteristics during three fencing-specific movements. *Journal of sports sciences , 29* (15), 1585–92.

Tsolakis, C., & Vagenas, G. (2010). Anthropometric, Physiological and Performance Characteristics of Elite and Sub-elite Fencers. *Journal of Human Kinetics , 23* (1), 89-95.

Tsolakis, C., & Vagenas, G. (2010). Anthropometric, Physiological and Performance Characteristics of Elite and Sub-elite Fencers. *Journal of Human Kinetics , 23* (1), 89-95.

Tsolakis, C., Bogdanis, G., Vagenas, G., & Dessypris, A. (2006). Influence of a twelve-month conditioning program on physical growth, serum hormones, and neuromuscular performance of peripubertal male fencers. *The Journal of Strength & Conditioning Research , 20* (4), 908-914.

Tsolakis, C., Kostaki, E., & Vagenas, G. (2010). Anthropometric, flexibility, strength-power, and sport-specific correlates in elite fencing. *Perceptual and motor skills , 110* (3), 1015-1028.

Tsolakis, C., Kostaki, E., & Vagenas, G. (2010). Anthropometric, flexibility, strength-power, and sport-specific correlates in elite fencing. *Perceptual and motor skills , 110* (3), 1015–1028.

Turner, A., Comfort, P., Moody, J., & Jeffreys, I. (2010). Neuroendocrinology and resistance training in adult males. *Professional Strength and Conditioning , 17*, 15-24.

Uchida, M., Teixeira, L., Godoi, V., Marchetti, P., Conte, M., Coutts, A., et al. (2014). Does The Timing of Measurement Alter Session-RPE in Boxers ? *Journal of Science and Medicine in Sport , 13* (1), 59-65.

Veerman, E., van den Keybus, P., Vissink, A., & Nieuw Amerongen, A. (1996). Human glandular salivas: their separate collection and analysis. *Eur. J. Oral Sci , 104* (1), 346—352.

Vincent, W. (1999). *Statistics in kinesiology* (3rd edition ed.). Champaign, Illinois: Human kinetics.

Viru, A., & Viru, M. (2003). Hormones in short-term exercises: Anaerobic events. *Strength Cond. J , 25*, 31-37.

Viru, A., Viru, M., & Bosco, C. (2003). Hormones in short-term exercises: Resistance and power exercises. *Strength Cond. J , 24*, 7-15.

Waldeck, M., & Lambert, M. (2003). Heart Rate During Sleep: Implications for Monitoring Training Status. *Journal of Sports Science and Medicine , 3*, 133-138.

Wallace, L., Slattery, K., & Coutts, A. (2009). The ecological validity and application of the session-RPE method for quantifying training loads in swimming. *Journal of Strength and Conditioning Research , 23* (1), 33-38.

Walsh, N., Blannin, A., Clark, A., Cook, L., Robson, P., & Gleeson, M. (1999). The effects of high-intensity intermittent exercise on saliva IgA, total protein and alpha-amylase. *J. Sports Sci , 17*, 134-129.

Weichenberger, M., Liu, Y., & Steinacker, J. (2012). A test for determining endurance capacity in fencers. *International Journal of Sports Medicine , 33*, 48-52.

West, D., Owen, N., Jones, M., Cook, C., Shearer, D., Newton, R., et al. (2011). Relationships between force–time characteristics of the isometric mid thigh pull and dynamic performance in professional rugby league players. . *The Journal of Strength & Conditioning Research , 25* (11).

Whiting, W., Gregor, R., & Halushka, M. (1991). Body segment and release parameter contributions to new-rules javelin throwing. *International Journal of Sport Biomechanics , 7*, 111-124.

Wilmore, J., & Costill, D. (2004). *Physiology of sport and Exercise* (3rd edition ed.). Champaign, IL: Human Kinetics.

Wilson, G., Lyttle, A., Ostrowski, K., & Murphy, A. (1995). Assessing Dynamic Performance: A Comparison of rate of force development. *The Journal of Strength & Conditioning Research , 9* (3), 176-181.

Winter, D. (2009). *Biomechnics and motor control of human movement* (Vol. 4). New Jersey, USA: John Wiley & Sons.

Wisloff, U., Stoylen, A., & Loennechen, J. (2007). Superior cardiovascular effect of aerobic interval training versus moderate continuous training in heart failure patients. *Circulation , 115*, 3086-94.

Wright, K., Hull, J., & Czeisler, C. (2002). Relationship between alertness, performance, and body temperature in humans. *." American Journal of Physiology-Regulatory, Integrative and Comparative Physiology , 283* (6), R1370-R1377.

Wylde, M., Frankie, H., & O'Donoghue. (2013). A time-motion analysis of elite women's foil fencing. *International Journal of Performance Analysis in Sport , 13*, 365-376.

Yamamoto, L., Judelson, D., Farrell, M., Lee, E., Armstrong, L., Casa, D., et al. (2008). Effects of hydration state and resistance exercise on markers of muscle damage. *The Journal of Strength & Conditioning Research , 22* (5), 1387-1393.

Yquel, R., Arsac, L., Thiaudiere, E., Canioni, P., & Manier, G. (2002). Effect of creatine supplementation on phosphocreatine resynthesis, inorganic phosphate accumulation and pH during intermittent maximal exercise. *Journal of Sports Sciences , 20* (5), 427-437.

Zatsiorsky, V. (2003). Biomechanics of strength and strength training. In P. Komi, *Strength and Power in Sport* (Vol. 2, pp. 114-133). Oxford, UK: Blackwell Science:.

Zatsiorsky, V., & Kraemer, W. (2006). *Science and Practice of Strength Training* (2nd Edition ed.). Human Kinetics.

Appendices

Appendix A. Ethics

Application for ethical approval, declaration form, participant information sheet (adult and child), consent form (adult and child), risk assessment, ethics approval letter

Appendix B. Published research articles emanating from this thesis

Turner, A., Miller, S., Stewart, P., Cree, J., Ingram, I., Dimitriou, L., Moody, J., Kilduff, L. (2013). Strength and Conditioning for Fencing. *Strength and Conditioning Journal , 35* (1), 1-9.

Turner, A., James, N., Dimitriou, L, Greenhalgh, A., Moody, J., Fulcher, D., Mias, E., Kilduff, L. (2014). Determinants of Olympic Fencing Performance and Implications for Strength and Conditioning Training. *Journal of strength and conditioning research , 28* (10), 3001-2011.

Appendix C. Manuscript rebuttal and clarification

Appendix D. Salimetrics protocols for the analysis of salivary analytes

Ptotocols for Testosterone, cortisol, alpha amylase and Immunoglobulin A are listed

Appendix E. Raw data from study 3

Raw data for each salivary analyte, and graphs illustrating hreart rate, rating of percieved exertion and blood lactae, across both tested competitions

Appendix D. Data from study 4

Table and Graphs illustrating weekly changes in training load (seperated by fencing and strength and conditioning), jump height, reactive strengt index, readiness to train questionaire scores and muscle soreness.

APPENDIX A

London Sport Institute
at Middlesex University

MIDDLESEX UNIVERSITY
SCHOOL OF HEALTH AND SOCIAL SCIENCES

HEALTH STUDIES ETHICS SUB-COMMITTEE

APPLICATION FOR ETHICAL APPROVAL OF CATEGORY A PROPOSALS

This form must be completed for all research projects carried out by staff or students of the School that conform to the Category A definitions.

Title of proposed study:

The Physiology and Biomechanics of Fencing

Name(s) and qualifications of supervisor(s) / principal investigator (s):

Prof Nic James, PhD

Name(s) and qualifications of researcher(s):

Anthony Turner, MSc, PGCE, ASCC, CSCS

Permanent contact details (address, email & telephone number):

40 The Reddings, Mill hill, London, NW7 4JR; a.n.turmer@mdx.ac.uk; 07815 321 922

Is the proposal linked to a programme of study? If so, please identify:

Yes, my PhD which is investigating 'The physiology and Biomechanics of Fencing'

Indicate the start and end date for the proposed study:

September 2011 – Sept 2016

Is the proposal externally funded? If so, name the source of the funding:

No

For information only(e.g. External NRES application) (If yes, *please state the name of the external ethics committee)*

Identify under which of the criteria in Category A of the guidelines this proposal can be classified:

A1*	(including Literature Review)	A2		A3
A4		A5	X	A6

London Sport Institute
at Middlesex University

DECLARATION FORM

(To be signed by **all**Supervisor(s)/Principal Investigator/Student Investigator)

Declaration (Principal investigator; Student Investigator; Student Supervisor):
Print Name (s):

Anthony Turner and Nic James

Declaration:

- As supervisor or principal investigator for this research study I understand that it is my responsibility to ensure that researchers/students under my supervision undertake a risk assessment to ensure that health and safety of themselves, participants and others is not jeopardised during the course of this study.
- I confirm that I have seen and signed a risk assessment for this research study using standard university forms and to the best of my knowledge appropriate action has been taken to minimise any identified risks or hazards.
- I understand that, where applicable, it is my responsibility to ensure that the study is conducted in a manner that is consistent with the World Medical Association Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects (see http://www.wma.net/e/policy/b3.htm).
- I confirm that I have reviewed all of the information submitted as part of this research ethics application.
- I understand that research records/data may be subject to inspection for audit purposes and I agree to participate in any audit procedures required by the SHSS ethics Committee if requested.

(1)…… **Date…01/08/11…….**

(2)…….. **Date 01/08/11……....**

(1) Signature of Supervisor(s) / Principal Investigator(s) (2) Student Researcher

You should submit one hard copy (signed by the research supervisor in the case of a student submission) and an electronic copy to Mrs Christine Constantinou, HSESC Secretary, at the Archway Campus (c.constantinou@mdx.ac.uk). This should be submitted at least **two weeks** before the date of the HSESC meeting

Students must remember to keep a copy of this form for inclusion in their project/dissertation report.

London Sport Institute
at Middlesex University

MIDDLESEX UNIVERSITY
SCHOOL OF HEALTH AND SOCIALSCIENCES

HEALTH STUDIES ETHICS SUB-COMMITTEE

PARTICIPANT INFORMATION SHEET (PIS) (adult)

1. Study title

The Physiology and Biomechanics of Fencing

2. Invitation paragraph

You are being invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

Thank you for reading this.

3. What is the purpose of the study?

This study aims to identify the physiological and biomechanical characteristics of Fencing. This will involve investigating the following variables:

1. Time-motion characteristics such as work to rest ratios, number of changes in direction, distance covered and common forms of attack
2. Fatigue and muscle damage induced during competition
3. Kinetics (forces) and kinematics (movement patterns) of Fencing specific movements such as the on guard position, lunge and fleche
4. Physical characteristics of Fencers, such as speed, agility and power

This data will be used to construct strength and conditioning training programmes and identify the differences, if any, between the three types of sword (epee, foil, sabre) and across age and gender.

This study will take place over approximately 5 years to cover the 2012 Olympics and preparation for the 2016 Olympics

4. Why have I been chosen?

You have been chosen as you are a British Fencing athlete. You will be one of approximately 100 athletes tested throughout the duration of this project.

5. Do I have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason.

6. What will happen to me if I take part?

This study involves collecting data on British Fencing athletes for approximately 5 years to cover the 2012 Olympics and the preparatory period of the 2016 Olympics. The tests you will undertake are the same as those used in sports such as rugby, soccer and various track and field disciplines and enable us to quantify the physical demands of competition and the physical characteristics of elite athletes (i.e., you). The tests involve us taking salivary and blood samples (the latter via a finger of ear lobe pin-prick), videoing your bouts and collecting fitness testing data.

You will be tested on several different occasions. You will be tested at two major competitions and then annually, at your national training camp, for the duration of this research or until you withdraw. The tests you will undergo are identified below in section 7.

Please note that in order to ensure quality assurance and equity this project may be selected for audit by a designated member of the committee. This means that the designated member can request to see signed consent forms. However, if this is the case your signed consent form will only be accessed by the designated auditor or member of the audit team.

7. What do I have to do?

Identified below are the tests (and methods) we will use the data of.

During one national and one international competition we will collect:
- Salivary samples (via an oral swab or passive drool) of cortisol and testosterone (markers of fatigue)
- Jump height (marker of fatigue)
- Blood samples (via a fingertip or earlobe 'pin-prick') of creatine kinase (marker of muscle damage) and lactate (marker of energy expenditure)
- Heart rate via a heart rate monitor
- Time-motion characteristics via video analysis

Annually, at each national training camp (or in a sport science laboratory) we will collect:
- Kinetic (force) and kinematic (movement) data on you while you perform three Fencing specific movements, the on guard position, the lunge and fleche. The methods we will use simply require us to attach markers to your clothing or skin that track how fast you move, your limb angles and the forces you produce.
- Fitness testing score i.e., jump height, speed, agility and strength.

Because testing will take place during competitions and training camps, you are not required to do anything out of the ordinary before testing. The testing protocols identified above are commonplace within many sports and it is likely that you already undergo several of these as part of your athlete training programme and profession.

The decision to not take part in this research should be made in collaboration with your coach and British Fencing as the results derived will help in your physical training programming (i.e., competition preparation) and that that of others.

8. What are the side effects of any testing received when taking part?

The 'pin prick' blood test may cause distress such as pain, infection, bruising and bleeding.

9. What are the possible disadvantages and risks of taking part?

Some testing protocols will require you to give up some of your own time, which would not otherwise be used when at training camps or competitions. This includes kinetic and kinematic measurements and the measurement methods used to assess competition fatigue.

10. What are the possible benefits of taking part?

We hope that participating in the study will help you, but this cannot be guaranteed. The information we get from this study may help us construct strength and conditioning programmes for Fencers and identify competition strategies aimed at minimising fatigue and enhancing power-endurance; it is hoped that the data will also help us provide appropriate rest and recovery between competitions and training camps.

11. Will my taking part in this study be kept confidential?

All information that is collected about you during the course of the research will be kept strictly confidential. Any information about you which is used will have your name and address removed so that you cannot be recognised from it.

All data will be stored, analysed and reported in compliance with the Data Protection Legislation of the UK.

12. What will happen to the results of the research study?

This research will be published as part of a PhD and will likely be available in 2017.To obtain a copy of the published results, you should contact the principal investigator, Anthony Turner (contact details below). Please note that individual athletes will not be identified in any report/publication.

13. Who has reviewed the study?

This study is reviewed by the following Research Ethics Committee: The Middlesex University, School of Health and Social Sciences, Health Studies Ethics sub-Committee.

14. Contact for further information

Principal Investigator: Anthony Turner: a.n.turner@mdx.ac.uk; 0208 411 4667
Director of Studies: Prof. Nic James: n.james@mdx.ac.uk; 0208 411
Contact address for both: London Sport Institute, Middlesex University, Hendon, NW4 4BT

Thank you for taking part in this study

All participants will be given a copy of the information sheet and a signed consent form to keep.

London Sport Institute
at Middlesex University

Participant Identification Number:

CONSENT FORM (adult)

Title of Project: The Physiology and Biomechanics of Fencing

Name of Researcher: Anthony Turner

1. I confirm that I have read and understand the information sheet dated .....……..…for the above study and have had the opportunity to ask questions. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason. ☐
3. I agree that this form that bears my name and signature may be seen by a designated auditor. ☐
4. I agree that my non-identifiable research data may be stored in National Archives and be used anonymously by others for future research. I am assured that the confidentiality of my data will be upheld through the removal of any personal identifiers. ☐
5. I agree to take part in the above study. ☐

Name of participant	Date	Signature
Name of person taking consent (if different from researcher)	Date	Signature
Researcher	Date	Signature

1 copy for participant; 1 copy for researcher

London Sport Institute
at Middlesex University

MIDDLESEX UNIVERSITY
SCHOOL OF HEALTH AND SOCIAL SCIENCES

HEALTH STUDIES ETHICS SUB-COMMITTEE

PARTICIPANT INFORMATION SHEET (PIS) (child)

1. Study title

The Physiology and Biomechanics of Fencing

2. Invitation paragraph

Your child is being invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

Thank you for reading this.

3. What is the purpose of the study?

This study aims to identify the physiological and biomechanical characteristics of Fencing. This will involve investigating the following variables:

1. Time-motion characteristics such as work to rest ratios, number of changes in direction, distance covered and common forms of attack
2. Fatigue and muscle damage induced during competition
3. Kinetics (forces) and kinematics (movement patterns) of Fencing specific movements such as the on guard position, lunge and fleche
4. Physical characteristics of Fencers, such as speed, agility and power

This data will be used to construct strength and conditioning training programmes and identify the differences, if any, between the three types of sword (epee, foil, sabre) and across age and gender.

This study will take place over approximately 5 years to cover the 2012 Olympics and preparation for the 2016 Olympics

4. Why have I been chosen?

Your child has been chosen as he/she is a British Fencing athlete; they will be one of approximately 100 athletes tested throughout the duration of this project. Because he/she is under 18, we will require parental consent.

5. Do I have to take part?

It is up to you to decide whether or not your child takes part. If you do decide to allow your child to take part you will be given this information sheet to keep and be asked to sign a

consent form. If you decide to allow your child to take part he/she is still free to withdraw at any time and without giving a reason.

6. What will happen to me if I take part?

This study involves collecting data on British Fencing athletes for approximately 5 years to cover the 2012 Olympics and the preparatory period of the 2016 Olympics. The tests your child will undertake are the same as those used in sports such as rugby, soccer and various track and field disciplines and enable us to quantify the physical demands of competition and the physical characteristics of elite athletes (i.e., you). The tests involve us taking salivary and blood samples (the latter via a finger of ear lobe pin-prick), videoing your bouts and collecting fitness testing data.

Your child will be tested on several different occasions. Your child will be tested at one major competition and then annually, at your national training camp, for the duration of this research or until you withdraw. The tests your child will undergo are identified below in section 7.

Please note that in order to ensure quality assurance and equity this project may be selected for audit by a designated member of the committee. This means that the designated member can request to see signed consent forms. However, if this is the case your signed consent form will only be accessed by the designated auditor or member of the audit team.

7. What do I have to do?

Identified below are the tests (and methods) we will use the data of.

During one national and one international competition we will collect:
- Salivary samples (via an oral swab or passive drool) of cortisol and testosterone (markers of fatigue)
- Jump height (marker of fatigue)
- Blood samples (via a fingertip or earlobe 'pin-prick') of creatine kinase (marker of muscle damage) and lactate (marker of energy expenditure)
- Heart rate via a heart rate monitor
- Time-motion characteristics via video analysis

Annually, at each national training camp (or in a sport science laboratory), we will collect:
- Kinetic (force) and kinematic (movement) data on your child while he/she perform three Fencing specific movements, the on guard position, the lunge and fleche. The methods we will use simply require you to attach markers to your clothing or skin that track how fast you move, your limb angles and the forces you produce.
- Fitness testing score i.e., jump height, speed, agility and strength.

Because testing will take place during competitions and training camps, your child is not required to do anything out of the ordinary before testing. The testing protocols identified above are commonplace within many sports and it is likely that your child already undergoes several of these as part of your athlete training programme and profession. The decision to not take part in this research should be made in collaboration with your

child's coach and British Fencing as the results derived will help in your physical training programming (i.e., competition preparation) and that that of others.

8. What are the side effects of any testing received when taking part?

The 'pin prick' blood test may cause distress such as pain, infection, bruising and bleeding.

9. What are the possible disadvantages and risks of taking part?

Some testing protocols will require your child to give up some of his/her own time, which would not otherwise be used when at training camps or competitions. This includes kinetic and kinematic measurements and the measurement methods used to assess competition fatigue.

10. What are the possible benefits of taking part?

We hope that participating in the study will help your child, but this cannot be guaranteed. The information we get from this study may help us construct strength and conditioning programmes for Fencers and identify competition strategies aimed at minimising fatigue and enhancing power-endurance; it is hoped that the data will also help us provide appropriate rest and recovery between competitions and training camps.

11. Will my taking part in this study be kept confidential?

All information that is collected about your child during the course of the research will be kept strictly confidential. Any information about your child which is used will have your child's name and address removed so that you cannot be recognised from it.

All data will be stored, analysed and reported in compliance with the Data Protection Legislation of the UK.

12. What will happen to the results of the research study?

This research will be published as part of a PhD and will likely be available in 2017.To obtain a copy of the published results, you should contact the principal investigator, Anthony Turner (contact details below). Please note that individual athletes will not be identified in any report/publication.

13. Who has reviewed the study?

This study is reviewed by the following Research Ethics Committee: The Middlesex University, School of Health and Social Sciences, Health Studies Ethics sub-Committee.

14. Contact for further information

Principal Investigator: Anthony Turner: a.n.turner@mdx.ac.uk; 0208 411 4667
Director of Studies: Prof. Nic James: n.james@mdx.ac.uk; 0208 411
Contact address for both: London Sport Institute, Middlesex University, Hendon, NW4 4BT

Thank you for taking part in this study

London Sport Institute
at Middlesex University

All participants will be given a copy of the information sheet and a signed consent form (to keep.

Participant Identification Number:

CONSENT FORM (child)

Title of Project: The Physiology and Biomechanics of Fencing

Name of Researcher: Anthony Turner

1. I confirm that I have read and understand the information sheet dated .....……..…for the above study and have had the opportunity to ask questions. ☐
2. I understand that my child's participation is voluntary and that I am free to withdraw him/her at any time, without giving any reason. ☐
3. I agree that this form that bears my name and signature may be seen by a designated auditor. ☐
4. I agree that my child's non-identifiable research data may be stored in National Archives and be used anonymously by others for future research. I am assured that the confidentiality of my child's data will be upheld through the removal of any personal identifiers. ☐
5. I consent to my child taking part in the above study. ☐

Name of participant (Name of parent/ guardian of participant)	Date	Signature
Name of person taking consent (if different from researcher)	Date	Signature
Researcher	Date	Signature

1 copy for participant; 1 copy for researcher

INDEPENDENT FIELD/LOCATION WORK RISK ASSESSMENT FRA1

This proforma is applicable to, and must be completed in advance for, the following field/location work situations:

1. *All field/location work undertaken independently by individual students, either in the UK or overseas, including in connection with proposition module or dissertations. Supervisor to complete with student(s).*
2. *All field/location work undertaken by postgraduate students. Supervisors to complete with student(s).*
3. *Field/location work undertaken by research students. Student to complete with supervisor.*
4. *Field/location work/visits by research staff. Researcher to complete with Research Centre Head.*
5. *Essential information for students travelling abroad can be found on www.fco.gov.uk*

FIELD/LOCATION WORK DETAILS

Name ………Anthony Turner.....

Student No
Research Centre (staff only)……..

Supervisor ……Prof Nic James…….

Degree course …MPhil……

Telephone numbers and name of next of kin who may be contacted in the event of an accident

NEXT OF KIN

Name …Carli Davy-Martin……..

Phone ……07931 716 140……..

Physical or psychological limitations to carrying out the proposed field/location work

…None…….……..……

…….……..……..……

……..

Any health problems (full details) Which may be relevant to proposed field/location work activity in case of emergencies.

…None.……..……..……

…….……..……..…….

Locality (Country and Region)

…Various Universities and sports centres (including London, Nottingham, Sheffield) but all within the UK……..

…….……..……..…….

Travel Arrangements

…Train or car……..

…….……..……..…….

NB: Comprehensive travel and health insurance must always be obtained for independent overseas field/location work.

…….……..……..……

……..

Dates of Travel and Field/location work

Conducted several times throughout the year and will largely depend on the calendar of British Fencing……

…….……..……..……

1

PLEASE READ THE FOLLOWING INFORMATION VERY CAREFULLY

Hazard Identification and Risk Assessment

List the localities to be visited or specify routes to be followed **(Col. 1).** For each locality, enter the potential hazards that may be identified beyond those accepted in everyday life. Add details giving cause for concern **(Col. 2).**

Examples of Potential Hazards :
Adverse weather: exposure (heat, sunburn, lightening, wind, hypothermia)
Terrain: rugged, unstable, fall, slip, trip, debris, and remoteness. Traffic: pollution.
Demolition/building sites, assault, getting lost, animals, disease.
Working on/near water: drowning, swept away, disease (weils disease, hepatitis, malaria, etc), parasites', flooding, tides and range.
Lone working: difficult to summon help, alone or in isolation, lone interviews.
Dealing with the public: personal attack, causing offence/intrusion, misinterpreted, political, ethnic, cultural, socio-economic differences/problems. Known or suspected criminal offenders.
Safety Standards (other work organisations, transport, hotels, etc), working at night, areas of high crime.
Ill health: personal considerations or vulnerabilities, pre-determined medical conditions (asthma, allergies, fitting) general fitness, disabilities, persons suited to task.
Articles and equipment: inappropriate type and/or use, failure of equipment, insufficient training for use and repair, injury.
Substances (chemicals, plants, bio- hazards, waste): ill health - poisoning, infection, irritation, burns, cuts, eye-damage.
Manual handling: lifting, carrying, moving large or heavy items, physical unsuitability for task

If no hazard can be identified beyond those of everyday life, enter 'NONE'.

1. LOCALITY/ROUTE	2. POTENTIAL HAZARDS
	None

The University Field/location work code of Practice booklet provides practical advice that should be followed in planning and conducting field/location work.

Risk Minimisation/Control Measures — PLEASE READ VERY CAREFULLY

For each hazard identified **(Col 2),** list the precautions/control measures in place or that will be taken **(Col 3)** to **"reduce the risk to acceptable levels",** and the safety equipment **(Col 5)** that will be employed.

Assuming the safety precautions/control methods that will be adopted **(Col. 3),** categorise the field/location work risk for each location/route as negligible, low, moderate or high **(Col. 4).**
Risk increases with both the increasing likelihood of an accident and the increasing severity of the consequences of an accident.

An acceptable level of risk is: a risk which can be safely controlled by person taking part in the activity using the precautions and control measures noted including the necessary instructions, information and training relevant to that risk. The resultant risk should not be significantly higher than that encountered in everyday life.
Examples of control measures/precautions:
Providing adequate training, information & instructions on field/location work tasks and the safe and correct use of any equipment, substances and personal protective equipment. Inspection and safety check of any equipment prior to use. Assessing individuals fitness and suitability to environment and tasks involved. Appropriate clothing, environmental information consulted and advice followed (weather conditions, tide times etc.). Seek advice on harmful plants, animals & substances that may be encountered, including information and instruction on safe procedures for handling hazardous substances. First aid provisions, inoculations,

individual medical requirements, logging of location, route and expected return times of lone workers. Establish emergency procedures (means of raising an alarm, back up arrangements). Working with colleagues (pairs). **Lone working is not permitted where the risk of physical or verbal violence is a realistic possibility.** Training in interview techniques and avoiding /defusing conflict, following advice from local organisations, wearing of clothing unlikely to cause offence or unwanted attention. Interviews in neutral locations. Checks on Health and Safety standards & welfare facilities of travel, accommodation and outside organisations. Seek information on social/cultural/political status of field/location work area.
Examples of Safety Equipment: Hardhats, goggles, gloves, harness, waders, whistles, boots, mobile phone, ear protectors, bright fluorescent clothing (for roadside work), dust mask, etc.

If a proposed locality has not been visited previously, give your authority for the risk assessment stated or indicate that your visit will be preceded by a thorough risk assessment.

3. PRECAUTIONS/CONTROL MEASURES	4. RISK ASSESSMENT (low, moderate, high)	5. SAFETY/EQUIPMENT
Taking blood and salivary samples. Use sterilised, single-use, disposable assays, gloves and lancets	Low	sterilised, single-use, disposable assays, gloves and lancets
Ensure testing area is clear and free from hazards	low	None

PLEASE READ THE FOLLOWING INFORMATION AND SIGN AS APPROPRIATE

DECLARATION: The undersigned have assessed the activity and the associated risks and declare that there is no significant risk or that the risk will be controlled by the method(s) listed above/over. Those participating in the work have read the assessment and will put in place precautions/control measures identified.

NB: Risk should be constantly reassessed during the field/location work period and additional precautions taken or field/location work discontinued if the risk is seen to be unacceptable.

Signature of Field/location worker (Student/Staff) …… **Date** ……01/08/11……..…

Signature of Student Supervisor ……..……..……..…… **Date** ……..……..…...

APPROVAL: (ONE ONLY)

Signature of Director of Programmes (undergraduate students only) **Date** ……01/08/11…….……..…

Signature of Research Degree Co-ordinator or Director of Programmes (Postgraduate) ……..……..……..…… **Date** ……..……..…

Signature of Research Centre Head (for staff field/location workers**)** ……..…… **Date** ……..……..…

FIELD/LOCATION WORK CHECK LIST

1. Ensure that **all members** of the field party possess the following attributes (where relevant) at a level appropriate to the proposed activity and likely field conditions:

- ☐ Safety knowledge and training?
- ☐ Awareness of cultural, social and political differences?
- ☐ Physical and psychological fitness and disease immunity, protection and awareness?
- ☐ Personal clothing and safety equipment?
- ☐ Suitability of field/location workers to proposed tasks?

2. Have all the necessary arrangements been made and information/instruction gained, and have the relevant authorities been consulted or informed with regard to:

- ☐ Visa, permits?
- ☐ Legal access to sites and/or persons?
- ☐ Political or military sensitivity of the proposed topic, its method or location?
- ☐ Weather conditions, tide times and ranges?
- ☐ Vaccinations and other health precautions?
- ☐ Civil unrest and terrorism?
- ☐ Arrival times after journeys?
- ☐ Safety equipment and protective clothing?
- ☐ Financial and insurance implications?
- ☐ Crime risk?
- ☐ Health insurance arrangements?
- ☐ Emergency procedures?
- ☐ Transport use?
- ☐ Travel and accommodation arrangements?

Important information for retaining evidence of completed risk assessments:

Once the risk assessment is completed and approval gained the **supervisor** should retain this form and issue a copy of it to the field/location worker participating on the field course/work. In addition the **approver** must keep a copy of this risk assessment in an appropriate Health and Safety file.

Middlesex University

School of Health and
Social Sciences
The Archway Campus
Furnival Building
10 Highgate Hill
London N19 5LW

Tel: +44 (0)20 8411 5000
www.mdx.ac.uk

To: Anthony Turner

Date: 22nd September 2011

Dear Anthony

Re: Anthony Turner - Application 789 – *'The Physiology and Biomechanics of Fencing.'* Category A5. Supervisor, Professor Nic James

Thank you for the response which adequately answers the ethics committee's queries. On behalf of the Health Studies Ethics sub-Committee, I am pleased to give your project its final approval. Please note that the committee must be informed if any changes in the protocol need to be made at any stage.

I wish you all the very best with your project.

Yours sincerely

Ms Dympna Crowley
Chair of Ethics Sub-committee (Health Studies)

Strength and Conditioning for Fencing

Anthony Turner, MSc, CSCS*D,[1] Stuart Miller, BSc (Hons),[1] Perry Stewart, MSc,[1] Jon Cree, MSc,[1] Rhys Ingram, MSc,[2] Lygeri Dimitriou, PhD,[1] Jeremy Moody, PhD,[3] and Liam Kilduff, PhD[4]
[1]London Sport Institute, Middlesex University, Wales, United Kingdom; [2]English Institute of Sport, Manchester, United Kingdom; [3]Sport Science, Cardiff Metropolitan University, Cardiff, United Kingdom; and [4]Sport and Exercise Science, Swansea University, Wales, United Kingdom

SUMMARY

SCIENTIFIC RESEARCH INTO FENCING IS SPARSE AND LITTLE RELATES TO STRENGTH AND CONDITIONING. IN OUR EXPERIENCE OF WORKING WITHIN FENCING, IT IS A PREDOMINATELY ANAEROBIC SPORT CHARACTERISED BY EXPLOSIVE HIGH-POWER MOVEMENTS. CONSEQUENTLY, FENCERS SHOULD BE CAUTIOUS OF SOME OF THE TRADITIONAL TRAINING METHODS CURRENTLY USED SUCH AS LONG SLOW DISTANCE RUNNING BECAUSE THIS IS LIKELY TO BE COUNTERPRODUCTIVE TO PERFORMANCE. INSTEAD, EXERCISES AND CONDITIONING DRILLS THAT DEVELOP REPEAT LUNGE ABILITY, STRENGTH, AND POWER SHOULD BE USED. THE HIGH PROPORTION OF LUNGING ALSO DICTATES THE NEED FOR ECCENTRIC STRENGTH AND CONTROL AND THE ABILITY TO REDUCE MUSCLE DAMAGE.

INTRODUCTION

Fencing is one of only a few sports that has been featured at every one of the modern Olympic Games. It takes place on a 14 × 2 m strip called a "piste," with all scoring judged electronically as a result of the high pace of competition. The winner is the first fencer to score 5 hits during the preliminary pool bouts, or 15 hits should they reach the direct elimination bouts. During the preliminary pools, bouts last up to 5 minutes, whereas during elimination, each bout consists of 3 rounds of 3 minutes, with 1-minute rest between the rounds. There are 3 types of swords used in Olympic fencing, and these are briefly described in Table 1. The sword with which a fencer chooses to specialize in is likely based on what is offered at their local club or the coach who first introduced them to the sport.

In general, fencing involves a series of explosive attacks, spaced by low-intensity movements and recovery periods, whereby perceptual and psychomotor skills prevail (i.e., the ability to quickly and appropriately respond to an opponent's actions). There is a great need to repeatedly defend and attack and to often engage in a seamless transition between the two (counterattack). This can be facilitated by an appropriate strength and conditioning (S&C) program in which strength, power, and power-endurance qualities (including economy of movement) can be enhanced. However, one common practice is that coaches favor the more "traditional" low-intensity, high-volume training, which is often contradictory to the scientific literature describing the development of these skills.

The aim of this article is to rationalize the use of S&C. A significant challenge stems from the lack of primary research conducted within fencing. Therefore, a combination of anecdotal observations (which include personal communications with the Great Britain coaching team) and evidence derived from empirically similar sports will need to be used. To complete this article, a fencing-specific S&C program will be suggested.

NEEDS ANALYSIS

As with any sport to which S&C interventions are to be implemented, the S&C coach must first undergo a needs analysis to identify the biomechanical and physiological requirements of the sport and its time-motion characteristics (TMC). After this, the S&C coach must construct an appropriate test battery to measure the strengths and weaknesses of the athlete against these variables. In addition, it is fundamental to identify the mechanisms of injury and rehabilitative strategies.

TIME-MOTION CHARACTERISTICS OF ELITE FENCERS

Fencing tournaments take place over an entire day (often lasting around 10 hours) and consist of approximately 10 bouts (the majority of which do not require the full bout time) with a break of anywhere between 15 and 300 minutes between each (20). Roi and Bianchedi (20) have reported the TMC of the winners of the men's and women's epee and men's foil during the elimination bouts of an international competition (Table 2). In general, results reveal that bouts and actual fight time consist of only 13 and 5% of actual competition time, respectively, with a bout work to rest ratio of 1 to 1 in men's epee and 1 to 3 in men's foil.

KEY WORDS:
fencing; combat; strength; power

BRIEF REVIEW

Determinants of Olympic Fencing Performance and Implications for Strength and Conditioning Training

Anthony Turner,[1] Nic James,[1] Lygeri Dimitriou,[1] Andy Greenhalgh,[1] Jeremy Moody,[2] David Fulcher,[3] Eduard Mias,[3] and Liam Kilduff[4]

[1]*Middlesex University, London Sport Institute, London, United Kingdom;* [2]*Cardiff Metropolitan University, Cardiff School of Sport, Wales, United Kingdom;* [3]*English Institute of Sport, Lee Valley Athletics Centre, London, United Kingdom; and* [4]*Applied Science Technology Exercise and Medicine (A-STEM), Swansea University, Swansea*

Abstract

Turner, A, James, N, Dimitriou, L, Greenhalgh, A, Moody, J, Fulcher, D, Mias, E, and Kilduff, L. Determinants of Olympic fencing performance and implications for strength and conditioning training. *J Strength Cond Res* 28(10): 3001–3011, 2014—Fencing is one of only a few sports that have featured at every modern Olympic games. Despite this, there is still much the sport science team does not know regarding competition demands and athlete physical characteristics. This review aims to undertake an analysis of the current literature to identify what is known, and questions that must be answered to optimize athlete support in this context. In summary, fencing is an explosive sport requiring energy production predominately from anaerobic sources. Lunging and change-of-direction speed seem vital to performance, and strength and power qualities underpin this. In the elimination rounds, fencers are likely to accumulate high levels of blood lactate, and so high-intensity interval training is recommended to reduce the intolerance to and the accumulation of hydrogen ions. Injury data report the hamstrings as a muscle group that should be strengthened and address imbalances caused by continuous fencing in an asymmetrical stance.

Key Words epee, foil, saber, lunge

Introduction

Fencing is one of only a few sports that have featured at every modern Olympic games. Fencing takes place on a 14 × 2-m strip called a "piste," with all scoring judged electronically because of the high pace of competition. The winner is the first fencer to score 5 hits during the preliminary pool bouts or 15 hits should they reach the direct elimination bouts. During the preliminary pools, bouts last for 5 minutes, whereas during elimination, each bout consists of 3 rounds of 3 minutes, with 1-minute rest between the rounds. In general, fencing involves a series of explosive attacks, spaced by low-intensity movements and recovery periods, predominately taxing anaerobic metabolism (44). Perceptual and psychomotor skills (i.e., the ability to quickly and appropriately respond to an opponent's actions) prevail, and there is a great need to repeatedly defend and attack, and often, engage in a seamless transition between the 2. There are 3 types of weapon used in Olympic fencing: foil, epee, and saber. In foil fencing, scoring is restricted to the torso; in epee, the entire body may be targeted; and in saber only hits above the waist count.

In order for sport science and the practitioners of its subdisciplines (e.g., biomechanics, physiology, and strength and conditioning) to support these athletes, a review of this sport must first be undertaken, addressing the available scientific research and synthesizing evidence based on competition demands and athlete physical characteristics. Such an analysis will help the sport science team in identifying the key components that lead to successful performance. This article aims to undertake this review and in doing so, describes competition demands according to 4 subsections: (1) time-motion analysis, (2) physiology, (3) biomechanics, and (4) incidence of injury. Athlete physical characteristics will subsequently be addressed. The article will then conclude with a perspective on future research and athlete testing protocols and training exercises.

Time-Motion Analysis of Elite Fencers

Fencing tournaments take place over an entire day (often lasting around 10 hours) and consist of around 10 bouts with a break of anywhere between 15 and 300 minutes between each bout (36). Roi and Bianchedi (36) have reported the time-motion analysis (TMA) data of the winners of the men's and women's epee and men's foil at an international competition. In general, results reveal that bouts and actual

Address correspondence to Anthony N. Turner, a.n.turner@mdx.ac.uk.

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Journal of Strength and Conditioning Research

APPENDIX C

Dear Editor-in-Chief,

We would like to write a manuscript clarification for the journal article entitled: Determinants of Olympic Fencing Performance and Implications for Strength and Conditioning Training by Turner et al. (2014) which was published in Volume 28 (10): 3001-3011. The authors have written a review on the strength and conditioning of fencing and have emphasised the lack of need for aerobic conditioning. This is a large theme throughout the article. We believe the authors have made some scientifically unsound conclusions from the data they have presented, in addition to some facts being inaccurate and misleading. On this basis Matthew Wylde and I would like some manuscript clarifications. Our main misgivings are outlined below:

1) It is very difficult to talk about strength and conditioning for fencing when there are 3 different weapon categories, which all have very different work to rest ratios as the authors allude to in the paper. It would be similar to writing an article on strength and conditioning for rugby and including both rugby league and rugby union codes in the article. For example, Epee has a much longer work to rest ratio than Sabre and would be more likely to be aerobic in nature. This would therefore have a big impact on the strength and conditioning requirements of Epee fencers.

2) While the authors have attempted to conduct a thorough review of the current literature, a number of papers highlighting the need for fencers to have a strong aerobic base (Koutedakis

et al., 1993; Sobczak and Smulsky, 2006; Bottoms et al., 2011; Weichenberger et al., 2012) have not been included.

3) The authors often refer to the low intensity nature of fencing during bouts and have provided data showing that heart rate levels and blood lactate levels are indeed reflective of submaximal exercise. This data shows the importance of aerobic metabolism during fencing. This is supported by an article by Bottoms et al. (2011) who demonstrated the importance of aerobic metabolism during fencing using gas analysis, yet this study was not alluded to in the text. With this in mind, it is surprising that the authors repeatedly state that aerobic conditioning is not important for fencing performance.

4) While the Wylde et al (2013) paper was discussed, the conclusions on the importance of aerobic fitness were omitted. Heart-rate data taken during actual competition was recorded at 90-95% of the fencers' maximum. In a 15-touch bout, which can last as long as 14-16 mins, aerobic fitness is essential to regulate the effects of fatigue brought on by this elevated heart-rate. In other sports it has been demonstrated that fatigue effects technique proficiency (Royal et al., 2006) and shot accuracy (Lyons et al., 2013). It is likely that a similar effect would be found in fencing, where technique proficiency and accuracy are essential components to success.

5) Within the first paragraph the authors state that a fight in the first round of a fencing match lasts 5 minutes, unfortunately this incorrect and it is actually 3 minutes. This could make a difference to the training undertaken by an athlete. In addition, they compare fencing to a boxing match and outline that boxing has 12 rounds where as in a direct elimination fight in fencing it is only 3 x 3 minutes. They are correct in saying this, however a fencing competition can last up to 10 hours with 6 x 3 minute fights in the first round which is followed by up to 8 direct elimination fights, which consist of 3 x 3 minutes and may last

longer if they go in to extra time. This shows there is indeed an importance for aerobic fitness to be able to recover from these fights in time for the next round. Thebault, Leger and Passelerque (2011) concluded that high aerobic fitness is a precious asset in counteracting fatigue in sports with numerous high intensity repetitions.

6) There is very little data on fencing and on each of the individual weapons. Before we can conclude that aerobic conditioning is not important we need to do more research. As far as we are aware a paper that Bottoms et al. wrote in 2011 entitled: Physiological responses and energy expenditure in epee fencing in elite female fencers, is the only paper to directly measure oxygen consumption during simulated fencing (this paper has not been included by the authors). The results from this showed that both aerobic and anaerobic capacity were important for fencing performance. More of these types of studies need to be undertaken to get a stronger understanding of the exact nature of fencing. Indeed, the research we did only looked at one simulated fight, the demands of aerobic metabolism could increase by the end of a 10 hour competition.

Authors biographies:

Dr Lindsay Bottoms is an Exercise Physiologist and also an International fencer, having gained a Bronze medal at the 2014 Commonwealth Fencing Championships.
Matthew Wylde is the Performance Analyst for the Fencing Academy at the Singapore Sports School.

References:

Bottoms, L.M., Sinclair, J., Gabrysz, T., Szmantlan-Gabrysz, U. and Price, M.J. (2011). Physiological responses and energy expenditure to simulated epee fencing in elite fencers. Serbian Journal of Sports Sciences, 5, 17-20.

Koutedakis, Y., Ridgeon, A., Sharp, N.C.C. and Boreham, C. (1993). Seasonal variation of selected performance parameters in epee fencers. British Journal of Sports Medicine, 27, 171-174.

Lyons, M., Al-Nakeeb, Y., Hankey, J. and Nevill, A. (2013). The Effect of Moderate and High-Intensity Fatigue on Groundstroke Accuracy in Expert and Non-Expert Tennis Players. Journal of Sports Science and Medicine, 12, 298-308.

Royal, K.A., Farrow, D., Mujika, I., Halson, S.L., Pyne, D. and Abernethy, B. (2006). The effects of fatigue on decision making and shooting skill performance in water polo players. Journal of Sports Sciences, 24, 807-814.

Sobczak, A. and Smulsky, V. (2006). Aerobic and Anaerobic Capacities of Different Age and Performance Female Fencers. Research Yearbook, 12, 214-217.

Thebault, N., Leger, L.A. and Passelerque, P. (2011) Repeated-sprint ability and aerobic fitness. Journal of Strength and Conditioning Research, 25(10):2857-65.

Weichenberger, M., Liu, Y. and Steinacker, J.M. (2012). A test for determining endurance capacity in fencers. International Journal of Sports Medicine, 33, 48-52.

Wylde, M.J., Tan, F.H.Y. and O'Donoghue, P.G. (2013) A time-motion analysis of elite women's foil fencing. International Journal of Performance Analysis of Sport, 13, 365-376.

Yours sincerely,

Dr. Lindsay Bottoms, PhD, Msc, Bsc (Hons), CSCS

Senior Lecturer in Exercise Physiology

School of Health, Sport and Bioscience,

University of East London

Manuscript Clarification

Thank you for raising these issues and the debate this has generated. Below we have responded to all your points, where our aim is to show that our contention is not with the need to develop an aerobic base, but rather the extent to which it should be developed and the methods used in achieving this. Also, while we recognize there are three swords, we will outline an argument that the strength and conditioning (S&C) programming for these does not differ. Naturally these are our inferences so at times it is not about disproving your argument, but rather presenting a logical alternative.

1. *Weapon specificity, i.e., there are three swords all must be trained differently.*

   We disagree. While it is safe to assume that the athlete of each weapon has varying degrees of speed, power and aerobic capacity, these differences are likely developed through the demands of actual sports training and competition. That is, the fencing coach of each sword wants the fencer to lunge, change direction, and recover as fast as possible, and also wants them to be lean and highly reactive etc. These are common goals across all swords and may explain why research in fencing typically looks to quantify the time of a lunge, or the speed of a movement etc., irrespective of sword (Gholipour, Tabrizi, & Farahmand, 2008; Gresham-Fiegel, House, & Zupan, 2013; Guilhem, Giroux, Chollet, & Rabita, 2014; Gutierrez-Davila, 2011; Stewart & Kopetka, 2005; Tsolakis & Vagenas, 2010; Tsolakis, Kostaki, & Vagenas, 2010); some studies do not even define the sword type (Tsolakis & Vagenas, 2010; Tsolakis, Kostaki, & Vagenas, 2010; Tsolakis, Bogdanis, Vagenas, & Dessypris, 2006). The S&C coach will thus train each component and aim to maximize the capacity of each. They could not train an epee fencer to be 70%

fast, while a foil and sabre fencer 80 and 90% respectively. Instead, the nature of their weapon will govern the extent of these adaptations. Epee is certainly more aerobic than sabre, so you would expect sabre to retain strength and power adaptations better, while these would compete and ultimately compromise with the muscle physiology of an epeeist who also requires additional endurance capacities. Finally, to use and interpret the meaning behind your analogy of rugby league vs. rugby union, we disagree again. In actual fact, and we would go one step further; you would find it difficult to identify the sport in question by merely looking at the S&C programme of any sport. There are countless examples of sports using squats, weightlifting, interval training and aerobic training for example, to improve the performance of their athletes. The difference is normally the frequency of each, rather than the type.

2. *Research papers alluding to the demands for an aerobic base in fencers*

It is important to note (and is stated in the paper), that our contention is not with the need to develop an aerobic base, but rather (1) the extent to which it should be developed (see page 3003, column two, paragraph two) and (2) the methods used in achieving this (see page 3004, column 2, paragraph one). You cite papers that support your argument to develop the aerobic capacity of fencers. In turn, they are refuted below, thus explaining their exclusion from our review.

Bottoms, et al., (2011).

This paper identifies the average VO_{2peak} in elite fencers as 46.9 ml/kg/min. We do not regard this as high, nor does it represent values attained by trained athletes in aerobic sports. Even the textbook of the National Strength and Conditioning Association (for whom this journal is affiliated) regards this value as untrained (Table 6.2, page 133) (Baechle & Earle) and is only slightly higher than that of weight lifters (45.3 ml/kg/min)

(MacFarlane, Northridge, Wright, & Dargie); additional data across sports is available in the review of Pluim et al., (2000). Furthermore, our paper states that we question the need to develop capacities in excess of 60 ml/kg/min. The value presented by Bottoms et al., (2011) is indeed low and would thus be increased, albeit indirectly by virtue of the high-intensity interval training we recommend based on several research papers (Baker, 2011; Helgerud, Hoydal, Wang, Karlsen, Berg, & Bjerkaas, Aerobic highintensity intervals improve VO2max more than moderate training, 2007; Wisloff, Stoylen, & Loennechen, 2007). Finally, we would also suggest that the values recorded by this paper do not actually represent competition data and that you have sold your argument short here. We find training based sparring to be significantly lower in intensity than competition bouts, likely on account of familiarity with the opponent, and the lack of arousal associated with insignificant win rewards (unpublished data that we aim to submit post Olympics 2016). We are therefore forced to manipulate sparring and fitness sessions to promote adaptations in this context.

Koutedakis, et al., (1993).

This paper merely identifies changes in aerobic capacity across a season. Its inclusion as a test is based on fencers having a significantly higher aerobic capacity than untrained, age matched controls. There is nothing to assume that this was related to performance and success. In fact, knowing the history of results and that these fencers were British (for whom I work for), it did not. While you may suggest that British fencers regularly win the Common Wealth Games, this is not regarded as an appropriate benchmark for success, given that there are no "high-level" competing nations; funded British fencers on the performance pathway do not typically compete at this (however, we certainly

acknowledge the prestige of this competition). In summary, this paper is not valid for supporting your argument.

Weichenberger & Steinacker, (2012).

The aim of this paper was to develop an aerobic test for fencers. It did not justify its validity and given the basis of our argument, it has none. This does not support the premise of your argument.

Sobczak & Smulsky, 2006.

We cannot find this resource

3. *Bottoms et al.,* (2011) *have shown that aerobic metabolism is important to fencing.*

   The paper of Bottoms et al., (2011) is refuted above and we believe, for the same reasons, invalidates the contention here.

4. *Fatigue effects shot accuracy and technical proficiency, and conclusions regarding the significance of the aerobic capacity reported by Wylde et al.,* (2013) *were omitted.*

   There is no argument here. We agree that fatigue effects technical proficiency and accuracy. However, high heart rates (which we too have measured in that range) do not imply an association like you suggest. Weight lifters have high heart rates across sets of their exercises.

Re your latter point, you are correct; we omitted the reference to developing an aerobic capacity. However, our conclusions are the same as this paper's, which we would

interpret to actually dispute your argument. Starting on page 373, paragraph four, it reads *"while long slow distance running may not be essential, aerobic endurance training should be integrated into elite fencing training, through bouts, lessons and endurance-oriented footwork. This sound aerobic base will enhance recovery between bouts and fights although not necessarily improve performance"*.

5. *Fencing matches last 3 min, not 5 min.*

   Apologies for the inaccuracy here, you are correct. We were over concise as pool bouts typically last 5 min as cited by most, including Wylde et al (2013) i.e., "*4-6mins*". However, we did state the length of the day is ~ 10 hours. This is probably the hardest part of fencing as (in our opinion) most confuse a competition duration of this length as justification for the training of high aerobic capacities. But as stated in our review paper (see page 3002, column one, paragraph one), and omitted from your argument, bouts and actual fight time consist of only 13 and 5% of the actual competition time, respectively. That means that for ~ 9 hours of that day, fencers are resting. We simply advise they "rest" better. For example, our training is about establishing what recovery and nutrition interventions we can do that fit the logistics of competition, and thus optimize subsequent bouts.

6. *More data on each weapon is needed*

   Agreed, more research is indeed needed, and we hope to publish additional data post Olympics to further our understanding.

Author Biography

Anthony Turner is the Programme Leader for the MSc in Strength and Conditioning at Middlesex University, London, England and is the head of Physical Preparation at British Fencing

References

Baechle, T., & Earle, R. *Essentials of Strength Trianing and Conditioning* (Vol. 3). Champaign, IL, USA: Human Kinetics.

Baker, D. (2011). Recent trends in high-intensity aerobic training for field sports. *Professional strength and conditioning , 22*, 3-8.

Bottoms, L., Sinclair, J., Gabrysz, T., Szmanthan-Gabrysz, U., & Price, M. (2011). Physiological responses and energy expenditure to simulated epee fencing in elite female fencers. *Serbian journal of sports sciences , 5* (1), 17-20.

Gholipour, M., Tabrizi, A., & Farahmand, F. (2008). Kinematics Analysis of Lunge Fencing Using Stereophotogrametry. *World Journal of Sport Sciences , 1* (1), 32-37.

Gresham-Fiegel, C., House, P., & Zupan, M. (2013). The effect of nonleading foot placement on power and velocity in the fencing lunge. *The Journal of Strength & Conditioning Research , 27* (1), 57-63.

Guilhem, G., Giroux, C. C., Chollet, D., & Rabita, G. (2014). Mechanical and Muscular Coordination Patterns during a High-Level Fencing Assault . *Medicine and science in sports and exercise , 46* (2), 341-50.

Gutierrez-Davila, M. (2011). Response timing in the lunge and target change in elite versus medium-level fencers. *European Journal of Sport Science* , 1-8.

Helgerud, J., Hoydal, K., Wang, E., Karlsen, T., Berg, P., & Bjerkaas, M. (2007). Aerobic highintensity intervals improve VO2max more than moderate training. *Medicine in Science and Sport and Exercise , 39*, 665-671.

Koutedakis, Y., Ridgeon, A., Sharp, N., & Boreham, C. (1993). Seasonal variation of selected performance parameters in épée fencers. *British journal of sports medicine , 27* (3), 171-174.

MacFarlane, N., Northridge, D., Wright, A. G., & Dargie, H. (1991). A comparative study of left ventricular structure and function in elite athletes. *British journal of sports medicine , 25* (1), 45-48.

Pluim, B., Zwinderman, A., van der Laarse, A., & van der Wall, E. (2000). The athlete's heart a meta-analysis of cardiac structure and function. *Circulation , 101* (3), 336-344.

Stewart, S., & Kopetka, B. (2005). The kinematic determinants of speed in the fencing lunge. *Journal of Sports Sciences , 23* (2), 105.

Tsolakis, C., & Vagenas, G. (2010). Anthropometric, Physiological and Performance Characteristics of Elite and Sub-elite Fencers. *Journal of Human Kinetics , 23* (1), 89-95.

Tsolakis, C., Bogdanis, G., Vagenas, G., & Dessypris, A. (2006). Influence of a twelve-month conditioning program on physical growth, serum hormones, and neuromuscular performance of peripubertal male fencers. *The Journal of Strength & Conditioning Research , 20* (4), 908-914.

Tsolakis, C., Kostaki, E., & Vagenas, G. (2010). Anthropometric, flexibility, strength-power, and sport-specific correlates in elite fencing. *Perceptual and motor skills , 110* (3), 1015–1028.

Weichenberger, M., Liu, Y., & Steinacker, J. (2012). A test for determining endurance capacity in fencers. *International Journal of Sports Medicine , 33*, 48-52.

Wisloff, U., Stoylen, A., & Loennechen, J. (2007). Superior cardiovascular effect of aerobic interval training versus moderate continuous training in heart failure patients. *Circulation , 115*, 3086-94.

Wylde, M., Frankie, H., & O'Donoghue. (2013). A time-motion analysis of elite women's foil fencing. *International Journal of Performance Analysis in Sport , 13*, 365-376.

APPENDIX D

Study 3.

Protocols by Salimetrics (see https://www.salimetrics.com/assay-kits) and used on the day of assay

Testosterone

Reagent preparation:

1. Saliva samples were completely thawed
2. Vortexed
3. Centrifuged @3000 rpm for 15 minutes
4. Samples were checked to ensure they were at room temperature before adding to assay plate
5. Samples were pipetted into appropriate wells
6. All reagents were brought to room temperature and mixed before use.
    a. A minimum of 1.5 hours was provided for the 18 mL of testosterone assay diluent to come to room temperature
7. Microtitre plate was checked to ensure it was at room temperature before use
8. 1X wash buffer was prepared by diluting Wash Buffer Concentrate 10-fold (10X) with room temperature deionized water (100 mL of Wash Buffer Concentrate (10X) to 900 mL of deionized water)
9. Serial dilutions of the Testosterone Standard were prepared as follows:
    a. Five polypropylene microcentrifuge tubes were labelled 2 through 6
    b. 90 µL of testosterone assay diluent was pipetted into tubes 2 through 6
    c. The standard was serially diluted 2.5X by adding 60 µL of the 600 pg/mL standard (tube 1) to tube 2, then mixed well
    d. After changing pipette tips, 60 µL was removed from tube 2 to tube 3 and again mixed well

e. This was continued for tubes 4, 5, and 6
f. The final concentrations of standards for tubes 1 through 6 were: 600 pg/mL, 240 pg/mL, 96 pg/mL, 38.4 pg/mL, 15.4 pg/mL, and 6.1 pg/mL respectively

Procedure:

1. Plate layout was determined using the manufacturer's template, with standards, controls, and saliva samples assayed in duplicate
2. 18 mL of testosterone assay diluent was pipetted into the disposable tube
3. 25 µL of standards, controls, and saliva samples was pipetted into appropriate wells
4. 25 µL of testosterone assay diluent was pipetted into 2 wells to serve as the zero
5. 25 µL of testosterone assay diluent was pipetted into each NSB well
6. The enzyme conjugate was diluted to1:1000 by adding 18 µL of the conjugate to the 18 mL tube of testosterone assay diluent
7. The diluted conjugate solution was immediately mixed and 150 µL was added to each well using a multichannel pipette.
8. The plate was mixed on a plate rotator for 5 minutes at 500 rpm and incubated at room temperature for a total of 1 hour
9. Using a plate washer, the plate was washed 4 times with 1X wash buffer. After the last wash, the plate was thoroughly blotted on paper towels before turning upright.
10. 200 µL of TMB Substrate Solution was added to each well with a multichannel pipette
11. It was then mixed on a plate rotator for 5 minutes at 500 rpm and the plate was incubated in the dark (covered) at room temperature for an additional 25 minutes
12. 50 µL of Stop Solution was then added with a multichannel pipette
13. It was then mixed on a plate rotator for 3 minutes at 500 rpm. It was mixed again if all wells had not turned yellow.
14. The bottom of plate was wiped with a water-moistened, lint-free cloth and wiped dry
15. It was then read in a plate reader at 450 nm and read within 10 minutes of adding Stop Solution

Calculations:

1. The average optical density (OD) was computed for all duplicate wells.

2. The average OD for the NSB wells was subtracted from the OD of the zero, standards, controls, and saliva samples.
3. The percent bound (B/Bo) for each standard, control, and saliva sample was calculated by dividing the OD of each well (B) by the average OD for the zero (Bo).
4. The concentrations of the controls and saliva samples were determined by interpolation using data reduction software (4-parameter non-linear regression curve fit)

Cortisol

Reagent preparation:

1. Saliva samples were completely thawed
2. Vortexed
3. Centrifuged @3000 rpm for 15 minutes
4. All reagents were brought to room temperature and mixed before use
5. A minimum of 1.5 hours was provided for the 24 mL of assay diluent to come to room temperature
6. Microtitre plate was checked to ensure it was at room temperature before use
7. 1X wash buffer was prepared by diluting Wash Buffer Concentrate 10-fold (10X) with room temperature deionized water (100 mL of Wash Buffer Concentrate (10X) to 900 mL of deionized water)

Procedure:

1. Plate layout was determined using the manufacturer's template, with standards, controls, and saliva samples assayed in duplicate
2. 24 mL of assay diluent was pipetted into the disposable tube
3. 25 µL of standards, controls, and saliva samples was pipetted into appropriate wells
4. 25 µL of assay diluent was pipetted into 2 wells to serve as the zero
5. 25 µL of assay diluent was pipetted into each NSB well

6. The enzyme conjugate was dilutted 1:1600 by adding 15 µL of the conjugate to the 24 mL tube of assay diluent
7. The diluted conjugate solution was immediately mixed and 200 µL was added to each well using a multichannel pipette
8. The plate was mixed on a plate rotator for 5 minutes at 500 rpm and incubated at room temperature for a total of 1 hour
9. Using a plate washer, the plate was washed 4 times with 1X wash buffer. After the last wash, the plate was thoroughly blotted on paper towels before turning upright
10. 200 µL of TMB Substrate Solution was added to each well with a multichannel pipette
11. It was then mixed on a plate rotator for 5 minutes at 500 rpm and the plate was incubated in the dark (covered) at room temperature for an additional 25 minutes
12. 50 µL of Stop Solution was then added with a multichannel pipette
13. It was then mixed on a plate rotator for 3 minutes at 500 rpm. It was mixed again if all wells had not turned yellow
14. The bottom of plate was wiped with a water-moistened, lint-free cloth and wiped dry
15. It was then read in a plate reader at 450 nm and read within 10 minutes of adding Stop Solution

Calculations:

5. The average optical density (OD) was computed for all duplicate wells.
6. The average OD for the NSB wells was subtracted from the OD of the zero, standards, controls, and saliva samples
7. The percent bound (B/Bo) for each standard, control, and saliva sample was calculated by dividing the OD of each well (B) by the average OD for the zero (Bo)
8. The concentrations of the controls and saliva samples was determined by interpolation using data reduction software (4-parameter non-linear regression curve fit)

Secretory IgA

Reagent preparation:

1. Saliva samples were completely thawed
2. Vortexed
3. Centrifuged @3000 rpm for 15 minutes
4. All reagents were brought to room temperature and mixed before use.
5. A minimum of 1.5 hours was provided for the 50 mL of SIgA Diluent Concentrate (5X) to come to room temperature
6. Microtitre plate was checked to ensure it was at room temperature before use
7. 1X wash buffer was prepared by diluting Wash Buffer Concentrate 10-fold (10X) with room temperature deionized water (100 mL of Wash Buffer Concentrate (10X) to 900 mL of deionized water)
8. 1X SIgA Diluent was prepared by diluting SIgA Diluent Concentrate (5X) 5-fold with room temperature deionized water (50 mL of SIgA Diluent Concentrate (5X) to 200 mL of deionized water)
9. Serial dilutions of the SIgA Standard were prepared as follows:
    a. Five polypropylene microcentrifuge tubes were labelled 2 through 6.
    b. 30 µL of 1X SIgA Diluent was pipetted into tubes 2 through 6.
    c. The standard was serially diluted 3X by adding 15 µL of the 600 µg/mL standard (tube 1) to tube 2, then mixed well
    d. After changing pipette tips, 15 µL was removed from tube 2 to tube 3 and again mixed well.
    e. This was continued for tubes 4, 5, and 6.
    f. The final concentrations of standards for tubes 1 through 6 were: 600 µg/mL, 200 µg/mL, 66.7 µg/mL, 22.2 µg/mL, 7.4 µg/mL, and 2.5 µg/mL respectively.

Procedure:

1. Plate layout was determined using the manufacturer's template, with standards, controls, and saliva samples assayed in duplicate
2. 3 mL of 1X SIgA diluent was pipetted into the disposable tube.

3. One small tube with the identity of each saliva sample was labelled
4. 100 µL of 1X SlgA diluent were pipetted into each of those tubes
5. 25 µl of saliva were pipetted into the appropriate tube and gently vortexed
6. One snap-cap tube (12 x 75 mm) for each standard, sample, and tube for the zero value was labelled, and 4 ml of 1X SlgA diluent were pipetted into each tube.
7. 10 µl of standard, and diluted saliva sample were pipetted into the appropriate tube.
8. 10µl of 1X SlgA diluent were pipetted into the zero value tube.
9. The antibody-enzyme conjugate was diluted 120 times with 1X SlgA diluent.
10. 50 µl of the diluted antibody-enzyme conjugate were pipetted into all tubes.
11. Each tube was gently vortexed and incubated for 90 minutes at room temperature.
12. At the end of the 90-min incubation each tube was gently vortexed again and 50µl of solution were pipetted into each well of the microtitre plate according to the pre-set template.
13. 50 µl of 1X SlgA diluent were pipetted into the NSB wells.
14. The plate was covered with an adhesive plate sealer and incubated at room temperature with continual mixing at 500 rpm for 90 minutes.
15. At the end of this 90-min incubation the plate was washed six times with 1X wash buffer. The washing was performed by gently adding wash buffer into each well with a squirt bottle, then decanting the liquid into a sink. After each wash, the plate was thoroughly blotted on paper towels before turning it upright.
16. 50 µl of TMB solution were pipetted into each well with a multichannel pipette.
17. The contents of the microtitre plate were mixed on a plate rotator for five minutes at 500 rpm and incubated in the dark at room temperature for an additional 40 min.
18. At the end of the 40 min incubation, 50 µl of stop solution were pipetted into each well with a multichannel pipette.
19. The contents of the microtitre plate were mixed again on a plate rotator for three minutes at 500 rpm. If the colour of some wells had not turned yellow, but blue-green colour had remained, mixing was continued until all samples had turned yellow.
20. The bottom of plate was washed off with a water-moistened lint-free cloth, and wiped dry, before being read in a Micro-plate reader using 450 nm.

Calculations:

1. The average optical density (OD) was computed for all duplicate wells.
2. The average OD for the NSB wells was subtracted from the OD of the zero, standards, controls, and saliva samples.

3. The percent bound (B/Bo) for each standard, control, and saliva sample was calculated by dividing the OD of each well (B) by the average OD for the zero (Bo).
4. The concentrations of the controls and saliva samples was determined by interpolation using data reduction software (4-parameter non-linear regression curve fit).
5. Concentrations of saliva samples were multiplied by 5 to obtain the final concentration of slgA in μg/ml.

Alpha Amylase

Reagent preparation:

1. Saliva samples were completely thawed
2. Vortexed
3. Centrifuged @3000 rpm for 15 minutes
4. All reagents were brought to room temperature and mixed before use.
5. Plate layout was determined using the manufacturer's template, with standards, controls, and saliva samples assayed in duplicate
6. Plate reader was set to incubate at 37ºC and to read in center measurement kinetic mode initially at one minute, then again two minutes later. 405 nm filter was chosen with no reference filter.
7. α-amylase substrate solution was heated to 37ºC in the trough provided.
8. Saliva samples were diluted with the α-amylase diluent provided. A 1:10 dilution of the saliva was prepared by pipetting 10 μL of saliva into 90 μL α-amylase diluent and mixed well. It was then further diluted by pipetting 10 μL of the 1:10 dilution into 190 μL α-amylase diluent (1:20); final dilution was 1:200.
9. 8 μL of controls and diluted saliva samples were added to individual wells.
10. 320 μL of preheated (37ºC) α-amylase substrate solution was added to each well simultaneously using a multichannel pipette.
11. Plate was immediately placed in the reader and initiated

Calculations

The one-minute reading was subtracted from the three-minute reading and multiplied by the conversion factor (see below). Results are expressed in U/mL.

$$\frac{\Delta Abs./min \times TV \times DF}{MMA \times SV \times LP} = U/mL \text{ of } \alpha\text{-amylase activity in sample}$$

Where:

- ΔAbs./min = Absorbance difference per minute
- TV = Total assay volume (0.328 mL)
- DF = Dilution factor
- MMA = Millimolar absorptivity of 2-chloro-p-nitrophenol (12.9)
- SV = Sample volume (0.008 mL)
- LP = Light path = 0.97 (specific to plate received with kit)

$$\frac{\Delta Abs./2 \times 0.328 \times 200}{12.9 \times 0.008 \times 0.97} = \Delta Abs. \times 328^{*} = U/mL \ \alpha\text{-amylase activity}$$

APPENDIX E

Study 3.

Raw data for each salivary analyte

	Cortisol nmol/L								
	A	**B**	**C**	**D**	**E**	**G**	**H**	**I**	**M**
48hr pre-comp one	23.4			8.4	8.8	15.4	4.7		**6.7**
24hr pre-comp one	17.5	14.0	29.6	16.2	12.4	23.6		9.3	9.6
30min pre-comp one	17.1	27.9	18.4	13.3	7.9	6.9		15.1	21.3
30min post-pools comp one	7.9	41.7	21.9	24.4	12.7	13.3		22.8	10.0
30min post-KO comp one			9.9	10.4	9.3				13.4
24hr post-comp one	20.1	17.6	9.0	5.5	7.3	10.9	14.1	10.1	4.3
48hr post-comp one		9.1	4.7	3.3	7.4		6.7		3.4
72hr post-comp one	24.5		7.1	7.8		10.7			6.6
48hr pre-comp two				7.8					
24hr pre-comp two	31.0	32.9	12.6	15.6		15.2	11.9	18.8	20.0
30min pre-comp two	19.1	22.5	21.0	19.5		22.1	35.1	26.4	21.2
30min post-pools comp two	4.9	45.0	21.6	20.9		7.5	29.9	28.2	6.5
30min post-KO comp two		4.2		8.4	8.5				6.2
24hr post-comp two			4.5	4.5					3.7
48hr post-comp two									
72hr post-comp two				4.6		19.3	16.8	16.7	5.8

	Testosterone (nmol/L)								
	A	**B**	**C**	**D**	**E**	**G**	**H**	**I**	**M**
48hr pre-comp one	801.3			540.4	501.7	509.3			323.6
24hr pre-comp one	989.2	576.7	408.7	493.4	271.8	503.5	292.9	422.5	391.3
30min pre-comp one	698.4	591.6	378.5	560.1	326.8	391.4		723.7	370.2
30min post-pools comp one	605.9	660.6	384.4	493.5	300.9	498.7		586.9	274.1
30min post-KO comp one			540.0	404.6	430.8				465.1
24hr post-comp one	870.3	728.6	551.7	405.6	261.8	420.3	660.0	450.1	321.8
48hr post-comp one		600.4	441.2	384.9	324.6		727.0		353.6
72hr post-comp one	1050.3		644.9	329.8		556.6			376.3
48hr pre-comp two				412.3					
24hr pre-comp two	820.2	710.1	730.4	576.1		574.9	425.1	330.8	503.8
30min pre-comp two	991.1	733.8	713.4	525.3		580.8	560.1	425.3	578.1
30min post-pools comp two	779.2	805.6	635.2	330.9		533.7	451.6	683.0	376.4
30min post-KO comp two		558.2		418.8	361.6				482.3
24hr post-comp two			439.0	342.4					324.3
48hr post-comp two									
72hr post-comp two				502.2		644.9	626.9	524.5	400.3

T/C ratio

	A	B	C	D	E	G	H	I	M
48hr pre-comp one	34.3			64.5	57.0	33.1			48.2
24hr pre-comp one	56.6	41.1	13.8	30.4	21.9	21.3	62.2	45.4	40.6
30min pre-comp one	40.9	21.2	20.6	42.2	41.6	57.0		47.9	17.4
30min post-pools comp one	76.9	15.9	17.6	20.3	23.7	37.5		25.7	27.5
30min post-KO comp one			54.3	39.0	46.5				34.8
24hr post-comp one	43.3	41.3	61.6	74.1	35.8	38.6	46.9	44.4	75.2
48hr post-comp one		65.8	93.5	115.1	43.9		108.1		105.4
72hr post-comp one	42.8		91.0	42.2		52.0			57.1
48hr pre-comp two									
24hr pre-comp two	26.5	21.6	57.8	36.9		37.8	35.6	17.6	25.2
30min pre-comp two	51.9	32.6	34.0	26.9		26.3	15.9	16.1	27.2
30min post-pools comp two	157.8	17.9	29.4	15.8		71.0	15.1	24.2	57.7
30min post-KO comp two		134.2		50.1	42.5				77.8
24hr post-comp two			97.1	76.5					88.4
48hr post-comp two									
72hr post-comp two				109.7		33.4	37.3	31.4	69.6

IgA (ug/ml)

	A	B	C	D	E	G	H	I	M
48hr pre-comp one	177.0			335	186	174			312
24hr pre-comp one	279.5	714	247	475	159	255	249	80	335
30min pre-comp one	299.0	270	268	415	193	138		347	273
30min post-pools comp one	269.5	353	261		144	279		245	230
30min post-KO comp one			406	223	364				200
24hr post-comp one	147.5	251	289	175	136	115	165	145	299
48hr post-comp one		313	226	261	146		189		216
72hr post-comp one	325.5		424	304		183			272
48hr pre-comp two				308					
24hr pre-comp two	247.5	235	404	343		143	168	133	283
30min pre-comp two	213.0	259	283	153		184	185		342
30min post-pools comp two	277.5	376	329	79		180	261	293	215
30min post-KO comp two		374		193	293				155
24hr post-comp two			286	120					191
48hr post-comp two									
72hr post-comp two				226		172	104	207	150

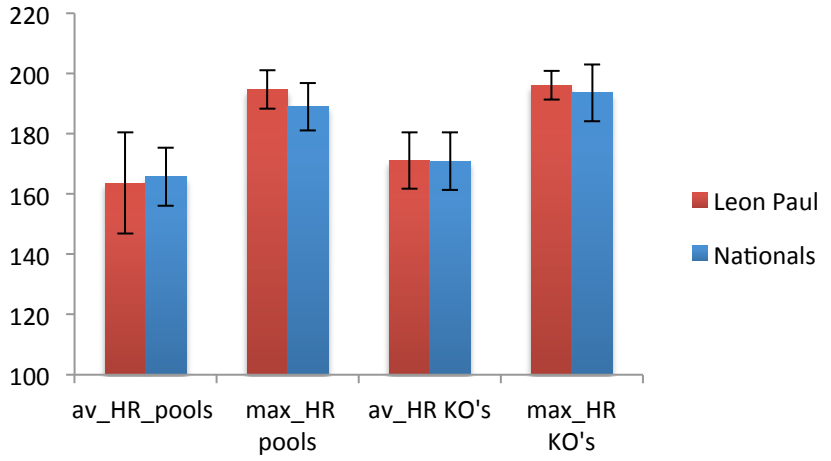
	Amylase								
	A	**B**	**C**	**D**	**E**	**G**	**H**	**I**	**M**
48hr pre-comp one	43.3			37.4	23.3	51.1			59.6
24hr pre-comp one	81.3	98.3	61.3	78.3	64.9	74.7	57.0	13.4	53.7
30min pre-comp one	178.6	71.8	92.4	99.9	175.3	131.1		70.1	138.3
30min post-pools comp one	133.7	182.8	62.6		114.0	111.4		95.0	185.1
30min post-KO comp one			25.2	68.8	27.2				23.6
24hr post-comp one	161.9	76.3	22.6	83.9	54.1	130.7	15.4	94.4	33.4
48hr post-comp one		56.4	22.6	56.0	62.3		9.8		41.9
72hr post-comp one	66.5		22.0	113.0		125.2			77.7
48hr pre-comp two				93.1					
24hr pre-comp two	56.7	42.3	281.1	86.5		85.5	10.5	6.6	71.1
30min pre-comp two	165.5	186.4	87.5	60.9		88.5	29.5	38.3	173.3
30min post-pools comp two	94.4	29.5	193.6	77.0		100.6	38.7	180.9	236.6
30min post-KO comp two		303.1		44.2	50.8				33.1
24hr post-comp two			40.3	102.6					48.2
48hr post-comp two									
72hr post-comp two				48.2		44.9	15.4	20.3	57.3

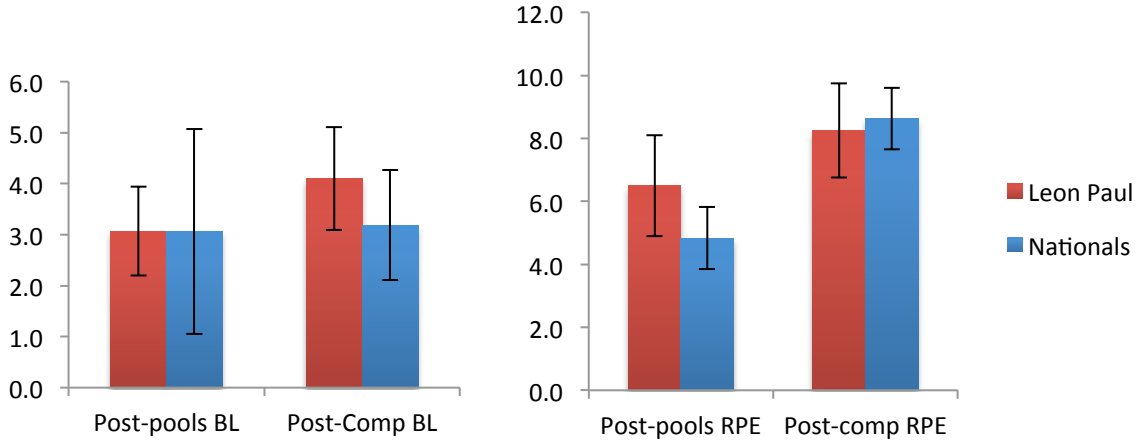
Salivary data (top) and jump data (bottom) presented as fold changes from baseline.

	TST		**Cort**		**TST/Cort**		**AA**		**IgA**	
Time point	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
24hr pre-comp	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
Pre-comp	1.11	0.67	1.29	0.20	1.16	0.46	2.41	1.29	1.08	1.38
Post-pools	1.04	0.70	1.31	0.27	1.39	0.58	4.01	1.44	1.22	2.98
Post-knockout	1.06	0.27	0.58	0.30	2.69	0.24	1.47	0.35	0.98	2.05
24hr post-comp	1.02	0.84	0.76	0.39	2.02	0.40	1.34	1.24	0.73	1.80
48hr post-comp	1.25	0.46	0.57	0.53	3.08	0.91	0.60	0.19	0.76	0.29
72hr post-comp	1.13	0.45	0.67	0.30	2.36	0.40	1.26	0.08	0.92	0.86

	CMJ height		CMJ PP		CMJ PRFD	
Time point	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
48hr pre-comp	1.00	0.00	1.00	0.00	1.00	0.00
Pre-comp	1.05	0.09	1.12	0.07	1.14	0.14
Post-pools	1.11	0.09	1.23	0.13	1.33	0.26
Post-knockout	1.12	0.11	1.24	0.18	1.32	0.31
48hr post-comp	0.91	0.08	0.93	0.11	0.92	0.27
72hr post-comp	0.94	0.09	0.95	0.10	0.87	0.31

HR (top), BL (bottom left) and RPE (bottom right) across each competition, separated by pools and knockout bouts.





APPENDIX F

Study 4.

Training load (also split according to S&C and Fencing), wellbeing (including soreness) and jump data (including changes from baseline) collected between Aug and Dec. Raw data represents averages as presented using pivot tables function in Excel.

Row Labels	Average of Total_TVL	Sum of S&C_TVL	Sum of Fencing_TVL	Average of Soreness	Average of RTQ	Average of CMJ_max	Average of RSI_Max	Average change CMJ_base	Average of RSI_BL
1	2368	1632	736	-0.26	0.90	35.44	1.58	0.00	0.00
2	2108	1423	685	-0.37	-1.29	35.33	1.61	-0.11	0.03
3	2264	1502	762	-0.28	1.70	34.90	1.49	-0.54	-0.09
6	3030	921	2109	-0.07	-0.48	38.47	1.63	3.03	0.05
7	3710	836	2874	-0.46	-0.69	39.01	1.70	3.57	0.12
8	3806	743	3063	-0.58	-1.50	40.44	1.79	5.00	0.21
9	4359	638	3721	-0.58	-1.00	39.98	1.89	4.54	0.31
10	4129	720	3409	-0.05	1.00	39.91	1.80	4.47	0.22
11	2736	672	2064	-0.33	-0.96	37.30	1.77	1.86	0.19
12	4160	532	3628	-0.38	-0.90	39.15	2.01	3.71	0.43
13	4443	603	3840	-0.48	-0.72	40.72	1.92	5.28	0.34
14	2406	421	1985	-0.32	-0.08	39.78	1.91	4.34	0.33
15	4323	360	3963	-0.21	0.56	41.03	2.04	5.59	0.46
16	4148	428	3720	-0.51	-0.31	40.29	2.07	4.85	0.49
17	3604	398	3206	-0.43	-0.44	39.32	1.98	3.88	0.40

Figures (top to bottom respectively) show changes in TL, jumping and wellbeing